I A SURVEY OF SOURCE MATERIALS

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Fascinating phenomena in nature like the brilliant moonlit sky studded with stars, the charm of the rising and setting Sun, the waxing and waning phases of the Moon, the periodical changes in the seasons and the like should obviously have excited the curiosity of early man. The origins of astronomy in India, as elsewhere in the world, have to be traced to the inquisitive interest which such phenomena excited in him and urged him to investigate the how and why thereof. The evolution of astronomical acumen, naturally enough, passed through several stages, including the feeling of wonder, mystery, continued observation, religious speculation, cosmic interpretation, scientific enquiry, derivation of rules for computation and development as a discipline.

The present survey of source materials on Indian astronomy is intended to indicate, in a chronological manner, the primary and secondary sources bearing on the development of the science of astronomy in India from the earliest times. Astronomy, unlike certain other disciplines like architecture and metallurgy, is more a science of observation and computation and therefore the main sources of information on its history have to be sought for in recorded literature, traditional practices, instruments and observatories, the last two relating to medieval and post-medieval periods.

ARCHAEOLOGICAL SOURCES

Large-scale excavations in the different regions of the Indian sub-continent, especially in the north-western region, during the last one hundred years, have unearthed substantial archaeological materials right from the Early Stone Age through the Middle and Late Stone Age to historical times. In the Mediterranean world neolithic culture, wherein sharp stone implements were used, and the chalcolithic culture, wherein copper and bronze implements had come into vogue, are clearly distinguished. In India, however, the two are often found to co-exist. This aspect was first identified in the excavations at Mohanjo-daro and Harappa on the Indus basin, for which reason that culture was called Indus Valley civilization. Later excavations proved the existence of this culture in places far removed from the Indus basin, extending to the entire north-west of India and part of Pakistan. The area included Cutch, Saurashtra and Gujarat in the south, Sind and Baluchistan in the west, East Panjab in Pakistan and Panjab and western U.P. in India, in the north, and northern Rajasthan in the east covering in all about 80,000 square miles. A series of excavations at Harappa have determined the norms of the civilization that existed in the area for which reason it is generally given the appellation

Harappan Culture. With this culture as the basis, the archaeological finds at Mohenjo-daro (Sind), Kot Diji (Sind), Kalibangan (Rajasthan), Lothal (Gujarat) and nearly 70 other sites, at different levels, are generally classified as Harappan, pre-Harappan and post-Harappan. Many of the finds have been subjected to Carbon-14 tests which have given dates ranging from 2300 to 2000 B.C.[1] Since recent researches have shown that radio carbon dates tend to be lower beyond 1000 B.C., the date of the pre-Harappan culture might have to be shifted to a few centuries earlier, to about 2500 B.C. or earlier.

Apart from extensive material including different types of pottery, stone and metal implements, faience, glass and beads, the above excavations have unearthed massive remains of towns and fortifications and nearly 3000 inscriptions and figures on terracotta seals.[2] Since during the early days of the evolution of astronomy observations would have been restricted to simple contrivances, besides the human eye any substantial remains could not be expected from archaeological sources. It is in the orientation indicated by the remains of constructions and the interpretation of select seals that one could look for any remains of astronomical importance.[3] However, more important and informative than the archaeological sources are the astronomical traditions of the earliest times recorded and preserved in Vedic literature the early strata of which go farther back than the excavated remains indicated above.

VEDIC LITERATURE

Nature of the Vedic corpus

The extensive Vedic literature spread over nearly 300 basic texts, forms, amongst other things, the primary source of information about the earliest stages of astronomical knowledge in India. A grand monument of the hoary past of the land, the Vedas have come down in a continuous and unbroken tradition, much better preserved than the religious literature, of any other ancient civilization. While most other religious canons have been composed at some specific period by an individual or a school, the Vedas are said to be revealed to 'Seers' of different ages, and handed down intact from generation to generation by oral transmission. This literature is amenable to be divided broadly, by contents and chronology, into four, viz. the *Saṃhitās, Brāhmaṇas, Āraṇyakas-Upaniṣads* and *Vedāṅgas.*

The Saṃhitās

The *Saṃhitās* are collections of hymns, prayers, invocations, charms, sacrificial formulae and the like, selected from a vast mass of floating material and arranged and classified according to content, utility or some other consideration. For each hymn or prayer so included, such documentation as its 'Seer', the deity invoked, the metre and the purpose are also indicated. There are four *Saṃhitās,* viz. the *Ṛgveda* or 'Book of Devotional Verse', the *Yajurveda* or 'Book of Sacrificial Formulae', the *Sāmaveda* or the 'Book of Psalms' and the *Atharvaveda* or the 'Book of Mystico-therapeutic Priestcraft'. It is to be noted that the pieces contained in these 'collections' are very much older than the time of their codification into the four *Saṃhitās,* having

been composed at different periods of time aud having been current by oral tradition when the pieces were selected and arranged in a definitive order.

The *Ṛgveda* is the oldest and the most important of the *Saṃhitās*. It comprises of 10,462 verses in 1028 hymns classified into 10 *maṇḍalas* according to the subject or the seer-families of the hymns. The *Yajurveda* is current in two traditions. The *Śukla* ('White'), available in two recensions, is entirely in verse, divided into 40 chapters, and the *Kṛṣṇa* ('Black'), current in four recensions, contains a large number of theological and other discussions and explanations in prose, interspersed with verses. The *Sāmaveda,* comprises of about 2000 verses, of which 1875 have been taken out of the *Ṛgveda* and the rest from elsewhere. It is arranged into four sections and set to music for being sung during sacrifices. The *Atharvaveda,* current in two recensions, contains about 6000 verses, put under 731 hymns, arranged into 20 sections. A seventh of the hymns of the *Atharvaveda* are common to those of the *Ṛgveda* and the work is nearly as important in the matter of antiquity and contents as the *Ṛgveda* itself.

The Brāhmaṇas

Next in order are the several *Brāhmaṇa* texts allied to each of the Vedic *Saṃhitās* and dealing mainly with the sacrificial rites, the ritualistic application of select passages from the relevant Veda and the speculation of the ideas underlying them. The important *Brāhmaṇa* texts are the *Aitareya* and *Sāṅkhāyana* related to the *Ṛgveda,* the *Śatapatha* of the *Śukla-Yajurveda, Taittirīya* of the *Kṛṣṇa-Yajurveda* and *Gopatha* of the *Atharvaveda*. The *Brāhmaṇas* are important for an understanding of the social, mythological and scientific thought-currents prevalent during the Vedic age.

The Āraṇyakas-Upaniṣads

The *Āraṇyaka* texts allied to the different *Saṃhitās* are concerned with the exposition of the symbolical significance of sacrificial ceremonies, and the *Upaniṣads* concern themselves with philosophical speculations and the exposition of the ways and means for the attainment of the highest values of life. Of the *Āraṇyakas,* the *Aitareya* and *Sāṅkhāyana* are related to the *Ṛgveda* and the *Taittirīya* to the *Kṛṣṇa-Yajurveda*. About 250 *Upaniṣads* are current, but only about a score of them belong to the Vedic age, the rest being later, aligning themselves to different schools of philosophy and later religious cults. There is not much information of astronomical significance in the *Āraṇyakas* and *Upaniṣads*.

The Vedāṅgas (Ancillary Vedic texts)

While the Vedic *Saṃhitās* set out the basic hymns and the *Brāhmaṇas* the sacrifices in which they are used, another set of texts called the *Vedāṅgas* helped in a proper understanding, interpretation and application of the hymns. Of the six *Vedāṅgas*, *Śikṣā* concerned itself with phonetics, *Vyākaraṇa* with grammar, *Chandas* with metre, *Nirukta* with etymology, *Kalpa* with the performances of rituals and *Jyotiṣa* with astronomy. Two of the six *Vedāṅgas,* are of significance to the history of astronomy. First, *Kalpa,* which consists of practical manuals on the performance of Vedic sacrifices

and household rituals, contain sections called *Śulba-sūtras* which, among other things, mention methods of orientation and make use of geometry, irrational numbers and other mathematical ideas in the construction of sacrificial altars. The other is the *Vedāṅga Jyotiṣa,* 'ancillary Vedic astronomy', of which three texts are available, related respectively, to the *Ṛgveda, Yajurveda* and the *Atharvaveda.* The first two, containing, respectively 36 and 43 verses, are ascribed to the same author Lagadha. Their basic content is almost the same, the latter having some additional matter, and form manuals for computing the civil calendar and proper times for the performance of rituals. The work locates the summer solstice in the middle of the constellation Āśleṣā and the winter solstice at the beginning of Dhaniṣṭhā, calculating backwards from the present position of the solstices, this would give a date *c.* 1370 B.C. The *Atharva Jyotiṣa,* which is in the form of a dialogue between Pitāmaha and sage Kāśyapa, in 162 verses, is astrological in content. Mention might be made here also of another work related to the *Atharvaveda,* viz. the *Nakṣatra-kalpa,* which enumerates 28 constellations from Kṛttikā, indicates their presiding deities, their groupings according to the part of the day and the directions and rituals pertaining to them; the work is thus astrological in content.

Nature of the astronomical content in Vedic texts

Though the Vedic poets did not compose the hymns for setting out scientific information, these extensive texts contain pertinent indication of the concepts and practices relating to the astronomy of the times. Especially significant in this regard are the cosmological hymns of the *Ṛgveda* and the *Atharvaveda.* Moreover, the recording, in some of the hymns, of celestial observations enables one to compute back, within margins, the date of composition of those hymns.

The lunar year was followed and the Moon was called *māsa-kṛt* 'maker of months.'[4] A full cycle of seasons delimited the year and the beginning of the year was ascertained by the proximity of a bright star to the full-moon which is clearly visible to the naked eye. Such stars recorded in different hymns of the *Ṛgveda* as the harbingers of autumn or the autumnal equinox are Aditi (Punarvasu, Pollux, long. 113°), Dakṣa (Abhijit, Vega, long. 284°), Rudra (Ārdrā, Betelguse, long. 88°) and Rohiṇī (Aedebaran, long. 69°). This change has obviously been the result of the precession of the equinoxes. Calculating at the rate of 72 years per degree, with due allowance for error, the periods referred to should, respectively, be *c.* 6200 B.C. 5400 B.C., 4350 B.C. and 3070 B.C. which should be the dates when the respective hymns were composed. A process of intercalation had also been in vogue for the correlation of the lunar year with the year of the seasons.[5]

The Ṛgvedic hymn 1.164, on the cosmic times wheel, by sage Dīrghatamas, speaks of a wheel of time, with a year consisting of twelve lunar months and 360 lunar days (*RV* 1.164.1) and starts the year with the autumn star Agni (Kṛttikā, Alcyon, long. 59°5) which on calculation gives a date *c.* 2350 B.C. In another Ṛgvedic hymn 3.99, which also mentions Kṛttikā as the autumn star (*c.* 2350 B.C.), sage Viśvāmitra worships 3339 (371×9) *devas* and apparently refers to a period of 30 years consisting of 371 lunar months. This would give an year of 371 lunar days, working out to

365.19 solar days.[6] Incidentally, it may be noted that in the above-cited hymns (*RV* 1.164 and 3.99), the numbers used (12, 360; 371, 3339. 33 and 11) have been expressed in the decimal system. Attention might also be drawn to the *Yajurveda*[7] enumerating multiples of 10 upto thirteen digits with specific names for each.[8]

While some of the stars are mentioned in the *Ṛgveda*, the *Yajurveda* and the *Atharvaveda* give full lists of the 27 (or 28) stars commencing from Kṛttikā. A fair knowledge of calendrical science is apparent in the full treatment of *gavām ayana* and other sacrifices of different durations based on the daily progress of the Sun. The equinoxes and solstices were determined accurately.[9] The twelve lunar months are named and so also the intercalary month. For ritualistic purposes the day-time had severally been divided into two, three, four, five and fifteen equal parts, each division having a different nomenclature. Of the five planets mentioned, only Jupiter (Bṛhaspati) and Venus (Vena) are referred to by name.[10],[11] The solar eclipse is described as the occultation of the Sun by Svarbhānu (Rāhu). P. C. Sen Gupta has determined the date of a total eclipse of the sun described in the *Ṛgveda* (5.40-4-9) as 3928 B.C.[12] It is interesting to note that the *Taittiriya Brāhmaṇa* (3.10.9) extols *nakṣatra-vidyā* ('science of stars') and mentions a hierarchy of scholars who cultivated the science.[13] Professional astronomers were termed *nakṣatra-darśa* 'star-gazer'[14] and *gaṇaka* 'calculator.'[15]

JAINA LITERATURE

Canonical Literature

The Jainas displayed extensive literary activity from early times and their canonical literature contain information on a wide range of subjects, religious, philosophical, social and scientific. The original texts, termed *Pūnva-s*, are said to have been lost and the Śvetāmbara sect of Jainas had them receast later in the Ardha-Māgadhī Prākṛt from existing fragments and oral tradition. Their basic canonical texts number 45 (or 50), besides a large number of subsidiary texts. The basic texts are classified as *Aṅgas, Upāṅgas, Prakirṇakas, Chedasūtras* and *Mūlasūtras*.

The *Aṅgas* are twelve in number and deal with doctrinal matter, rituals, legends and the like. They are the *Ācārāṅga, Sūtrakṛtāṅga, Sthānāṅga, Samavāyāṅga, Bhagavati* or *Vyākhyāprajñapti, Jñātṛdharmakathā, Upāsakadaśā, Antakṛtadaśā, Anuttara-aupapātikadaśā, Praśna-vyākaraṇa, Vipākasūtra* and *Dṛṣṭivāda*. Of these, the *Sthānāṅga* and *Bhagavatisūtra* contain information on mathematics and astronomy.

There are twelve *Upāṅgas* corresponding to the *Aṅgas*, but not directly related to them. These are: *Aupapātika, Rājapraśnīya, Jivājivābhigama, Prajñāpanā, Sūryaprajñapti, Jambūdvipaprajñapti, Candraprajñapti, Nirṇayāvali, Kalpāvataṃsikā, Puṣpikā, Puṣpacūlikā* and *Vṛṣṇidaśāḥ*. Among these, Jaina cosmogony is dealt with in *Jivājivābhigama* and *Jambūdvipaprajñapti* and details of Jaina astronomy are to be found in *Sūryaprajñapti* and *Candraprajñapti*, and also in *Jambūdvipaprajñapti*.

The third set of texts called *Prakirṇakas*, 'Miscellaneous texts', are ten in number, and like the *Pariśiṣṭas* (ancillary texts) of the Vedas, treat of numerous matters related

to the canon. One of these texts, the *Tandulaveyālīya* contains, among other things, measures of length and of time.

There are nine *Chedasūtras* which deal with the rules of conduct and life of monks and nuns, monastic jurisprudence and edificatory legends.

Extensive and highly important from the point of contents are the four *Mūlasūtras,* viz. *Uttarādhyāyana, Āvaśyaka, Daśavaikalika* and *Piṇḍa-niryukti,* of which the first one contains occasional passages ralating to mathematics and astronomy.

Two individual texts called *Cūlikāsūtras* of an encyclopaedic nature, the *Nandi-sūtra* and *Anuyogadvārasūtra,* sometimes included in the *Prakīrṇakas,* make up the Śvetāmbara canon. These texts deal with numerous topics, including topics on astronomy and mathematics, which a Jaina monk was supposed to know.

Chronology of the Jaina canon

Jaina tradition holds that the canon taught by Mahāvīra Jina was dutifully handed down for six generations and, when it tended to lapse into oblivion, a Council was called at Pataliputra when the 12 *Aṅgas* were resuscitated. When it was again thrown into disorder, another Council was held at Vallabhi in the 6th century A.D. and it was again reconstructed. Detailed analysis of the contents and language of the canon as it exists would show that the most ancient portions took shape during the third and fourth century B.C.

The Jaina canonical texts are highly repetetive and numerous passages are common to different texts. The several topics dealt with in the Jaina canons were later classified by Āryarakṣita (by Samantabhadra according to some) and arranged into four collections entitled *Caraṇānuyoga, Dharmakathānuyoga* (or *Prathamānuyoga*), *Gaṇitānuyoga* (or *Karaṇānuyoga*) and *Dravyānuyoga.* Matters relating to astronomy, mathematics, geography and allied subjects have been collected in the *Gaṇitānuyoga.*

The Jaina canons speak of astronomy as an important branch of study and as an essential equipment for a Jaina priest for computing the correct time for religious performances. The *Sūryaprajñapti, Candraprajñapti* and *Jambūdvipaprajñapti,* give a full depiction of the astronomical concepts and practices of the Jainas. The first two texts are entirely devoted to the subject, while the third, which is an extensive work divided into seven sections, devotes its last section for astronomy; it also enumerates, in section two, forty-five divisions of time, commencing from *asaṅkhyāta,* being 'inscrutable infinitismal time', to *śirṣaprahelikā,* which is equal to several crores of years. The astronomical material contained in all these three works is almost the same in essence.

Extensive expositions are also available for the above works. For the *Sūryaprajñapti* there is a commentary by the versatile Jaina scholiast Malayagiri (*c.* 1100-1200 A.D.) and a *Nirukti* by Bhadrabāhu, which latter is known only through quotations. *Candraprajñapti* too has been commented on by Malayagiri. For the

Jambūdvīpaprajñapti, Malayagiri's commentary is known only through quotations, but a detailed commentary by Śānticandra (16th cent. A.D.) is available. Padmanandi, an author of *c.* 1000 A.D., has abridged the work in his *Jambūdvīpaprajñapti-saṃgraha*.

Post-canonical Jaina Literature

Post-canonical Jaina literature is very voluminous and encompasses all disciplines. A brief mention might be made here of the more important writings relating to astronomy.

The *Tattvārthādhigama-sūtra* of Umāsvāti (A.D. 185-219) contains a section on cosmology, which deals with astronomy as well. Commentaries on this work are available by Umāsvāti himself and by later scholars. The *Trilokaprajñapti* by Yati-Vṛṣabha (between A.D. 473 and 609) is an encyclopaedic work in 7000 verses and, in its chapter seven, there is a long excursus on astronomy. It is noteworthy that the treatment of the subject here exhibits considerable parallelisms in thought and expression with the *Āryabhaṭīya.*[16] *Jyotiṣakaraṇḍaka,* possibly by an early author by name Padaliptācārya, is based on the *Sūryaprajñapti* and contains the entire gamut of Jaina astronomy. The work has been commented on by Malayagiri who quotes earlier commentaries also. The *Karaṇānuyoga* or *Gaṇitānuyoga* of the Digambara seet of Jainas is again a compilation of astronomical and mathematical material scattered in the different Jaina texts, including *Sūrya*-and *Candraprajñapti* and *Jayadharalā.*

Among later Jaina works on astronomy the undermentioned are noteworthy: *Jyotissāra* by Thakker Pheru (14th cent.) in 238 verses, divided into four chapters; *Dinaśuddhi* by Ratnaśekhara Sūri (15th cent.) in 144 verses for computing the true Sun, Moon etc., *Maṇḍalaprakaraṇa* by Vinayakuśala in 99 verses, composed in A.D. 1596, with an elaborate commentary: *Jyotiḥprakāra* by Jñānabhuṣaṇa (*c.* A.D. 1700) in seven sections, and *Candrārkī* by Dinakara (16th cent.) on the computation of true Sun and Moon and its commentary by Kṛpāvijaya.

A few works on astronomical instruments produced by Jaina astronomers under Muslim inspiration are also known. These include *Yantrarāja* by Mahendra Suri (A.D. 1348) who was a courtier of Sultan Feroz Shah Tughlaq, and its commentary by Malayendu Sūri, and *Ustaralaya-yantra* by Meghalaya (*c.* A.D. 1500 in the construction and use of astrolabe, with a commentary by the author himself. Among manuals on astronomy by Jaina authors, a mention might be made of *Karaṇarāja* in ten sections by Muni Sundara (*c.* A.D. 1600). A number of *Pañcāṅga* manuals for the computation of the daily calendar are also known to be composed by later Jaina scholars.

ASTRONOMICAL SIDDHĀNTAS

Nature of the Siddhāntas

The few centuries immediately preceding and following the Christian era are of significance in the history of Indian astronomy inspite of the fact that practically no important work on astronomy of the times has come down to us intact, but for the

Jaina texts mentioned earlier. The reasons are not far to seek. This was a period when the Vedic age evolved into the classical age at the advent of Buddhism and Jainism and the direct contact with the Greeks and the Romans. The unorthodox bent of thought and new sources of knowledge should have had their impact upon the intellectual endeavours of the Vedic Indians, resulting in novel strides in all walks of life including the pursuit of sciences. In the discipline of astronomy, this period witnessed the advent of a class of texts called *siddhāntas,* characterized by a better scientific approach and more comprehensive treatment. The *siddhānta* astronomy adopted more sophisticated mathematics, incorporated the planets in the system, devised a system of coordinates for the determination of the periods of planetary revolutions and of the relative sizes of the Earth, the Sun and the Moon. The *nakṣatra* system was dispensed with and replaced by the twelve signs of the zodiac. The mean longitudes were calculated from the number of days elapsed from the beginning of long periods of time called *Kalpa* or the *Kaliyuga.* The length of the year and day-lengths were correctly determined. Planetary positions were computed using eccentrics and epicycles. The eclipses were computed with greater accuracy by correcting the results for parallax. Computations were characterized also by geometrical, arithmetical and algebraic practices, some aspects of plane and spherical trigonometry, and application of indeterminate equations.

Early Siddhāntas

According to tradition, there existed 18 early *siddhāntas* composed by Sūrya, Pitāmaha, Vyāsa, Vaśiṣṭha, Atri, Parāśara, Kāśyapa, Nārada, Garga, Marīci, Manu, Aṅgiras, Lomaśa (Romaka), Pauliśa, Cyavana, Yavana, Bhṛgu and Śaunaka. Most of these have gone out of vogue and lost, but five are available in the form of summaries or, what is more likely, extracts, in the *Pañcasiddhāntikā* of the prolific writer of astrology Varāhamihira (A.D. 578), being the *siddhāntas* of Pitāmaha Vaśiṣṭha, Pauliśa, Romaka and Sūrya. The *Sūryasiddhānta* is available also in a later modified form. The reason for the disappearance of the early *siddhāntas* is to be sought in their supercession by later *siddhāntas* characterised by greater accuracy, easier methods of calculation and comprehensiveness. The non-availability of the early *siddhāntas* in their full and original form makes it difficult to reconstruct the development of the discipline during this period.

Later Siddhāntas

The later *siddhāntas* followed, in the main, the general pattern of the earlier *siddhāntas,* but there was substantial development in the matters covered, the range of date used and the manner in which the subject was set out. For various reasons, the schools represented by the different *siddhāntas* came to be popular in different parts of the country, where texts in extension, expositions, systems of computation, practical manuals *(Karaṇas),* astronomical tables *(Koṣṭhakas),* description of instruments *(yantras)* and other miscellaneous writings, came to be composed, mainly in Sanskrit, but also in the different provincial languages.

The *Āryabhaṭīya* of Āryabhaṭa I (b. A.D. 476) is the earliest of the later *siddhāntas.* In 121 verses, divided into four chapters, it sets out: Ch. I. The astronomical

constants and the sine table; II. Mathematics required for computations; III. Division of time and rules for computing the longitudes of planets using eccentrics and epicycles; and IV. The armillary sphere, rules relating to problems of trigonometry and the computation of eclipses. The *Āryabhaṭīya* started a new school of astronomy which grew popular in South India and threw up extensive literature, both expository and original.

The *Āryabhaṭīya*, the parameters and other astronomical elements of which constituted *Āryapakṣa*, had its epoch at sunrise at Laṅkā, at the commencement of the Kaliyuga, on Friday, 18 February 310 B.C. Āryabhaṭa wrote still another work, apparently entitled *Āryabhaṭasiddhānta*, which had its epoch at midnight 17/18 February 310 B.C. and formed the basis for the *Ārdharātrikapakṣa* in Indian astronomy. The text of this work is not available now, but is known through quotations and a summary of its tenets mentioned in later works.[17]

The earliest available commentary on the *Āryabhaṭīya* is by Bhāskara I who wrote from Valabhi in Gujarat (A.D. 629), but he names earlier exponents of the school like Lāṭadeva and Pāṇḍuraṅgasvāmī. Other scholiasts of the *Āryabhaṭīya* include Someśvara (11th-12th cent.), also from Gujarat, and several from South India, including Sūryadeva Yajvan (b. 1191), Parameśvara (*c.* 1450), Yallaya (1480), Nīlakaṇṭha Somayāji (b. 1444), Raghunātha Rājā (1597), Ghaṭīgopa (*c.* 1800) and Bhūtaviṣṇu. Bhāskara I wrote also two authoritative works on the system of Āryabhaṭa, the *Mahābhāskarīya* and the *Laghubhāskarīya*, in eight chapters each. These texts too have been elaborately commented upon, the former by Govindasvāmin (*c.* 800-850) with a super commentary by Parameśvara, Sūryadeva Yajvan, Parameśvara and in *Prayogaracanā* by an anonymous author. The *Laghubhāskarīya* has been commented by Śaṅkaranārāyaṇa (A.D. 869), Udayadivākara (A.D. 1073) and Parameśvara.

The *Brāhma-sphuṭa-siddhānta* of Brahmagupta (b. 598) exerted great influence in the astronomical thought of western and northern India as works based on it would show. In 1008 (or 1022) verses, divided into 24 (or 25) chapters, it expounds the *Brahmapakṣa* and criticises the *Āryapakṣa* of Āryabhaṭa. Chapter 11 and 22 are important for the reason that in the former he criticizes the views of some of his predecessors, including Āryabhaṭa, Pradyumna, Lāṭadeva, Varāhmihira, Vijayanandin, Viṣṇucandra's *Vāśiṣtha-siddhānta*, Śrīṣeṇa's *Romaka-siddhānta*, and the Jainas, and in the latter gives details of astronomical instruments. Pṛthudakasvāmin (*c.* 860) wrote an erudite commentary on the work, in which he quotes an earlier commentary by Balabhadra. Other commentators of *Brāhma-sphuṭa-siddhānta* are Āmarāja, Bhaṭṭotpala, Lalla, Someśvara, Śrīdatta and Varuṇa. This siddhānta was taken to Baghdad where it was translated into Arabic under the title, *Al-Zīj-al-Sindhind* in A.D. 771 or 773 by Muhammad ibn Ibrahim al-Fazārī.[18]

A '*Later Pauliśa-siddhānta*', which adopts the parameters of the *Ārdharātrikapakṣa* but makes major improvisations otherwise is known from citations occurring in the works of Pṛthūdakasvāmin, Bhaṭṭotpala, Āmarāja and Al-Bīrūnī.[19]

The *Śiṣyadhīvṛddhida-tantra* of Lalla (8th-19th cent.) in 12 chapters, is based on the *Ārdharātrikapakṣa* of Āryabhaṭa, but incorporates *bīja*-corrections and makes certain improvisations from the *Brāhmasphuṭa-siddhānta*. It contains an informative chapter on astronomical instruments and has been commented upon by Bhāskara II (b. 1114) and by Mallikārjuna Sūri (12th cent.).

The *Later Sūryasiddhānta*, a comprehensive work in 12 chapters, has been highly popular throughout India. It adopts the *Ārdharātrikapakṣa* but makes modifications. Among its large number of commentaries might be mentioned those of Mallikārjuna Sūri (12th cent.), in Telugu and Sanskrit, Caṇḍeśvara (12th cent.), Madanapāla (14th cent.), Parameśvara (1432), Yallaya (1472), Rāmakṛṣṇa Ārādhya (1472), Bhūdhara (1572), Tamma Yajvan (1599), Raṅganātha (1603), Nṛsiṃha (1611), Viśvanātha (1628), Kamalākara (17th cent.) and Dādābhāi [20] (18th cent.).

The *Vaṭeśvara-siddhānta* by Vaṭeśvara (A.D. 904) follows the *Āryapakṣa* and *Saurapakṣa* and gives a thorough treatment of astronomy in three sections. A point of interest in the work is that, as an ardent admirer of Āryabhaṭa, Vaṭeśvara vehemently criticizes Brahmagupta and refutes his views in ch. 10 of Sn. I of the work.

Śrīpati's *Siddhāntaśekhara* (A.D. 999), which, in 20 chapters, follows the *Brahmapakṣa* is important in that it gives rules for determining the moon's second inequality and evection. An incomplete commentary on the work by Makkibhaṭṭa is available in print.

The *Siddhānta-Śiromaṇi* (A.D. 1150) of Bhāskara II, who hailed from the Karnataka region, is by far the most comprehensive *siddhānta* work in Indian astronomy. It is based on the *Brahmapakṣa*. The work is in four parts: I. *Līlāvati* on arithmetic, II. *Bījagaṇita* on algebra, and III. *Gaṇitādhyāya* and IV. *Golādhyāya*, on astronomy. The epicyclic-eccentric theories are fully developed to account for planetary motions. The section on astronomical instruments is also more full than earlier treatises. The four parts of the work have also been studied independent of each other. All these have been supplied elucidative glosses, called *Vāsanā-bhāṣya* by the author himself. About 50 other commentaries are known for the *Līlāvatī* and the other parts have also been commented by several scholiasts. The more important commentaires in *Gaṇitādhyāya* and *Golādhyāya*, which form the astronomical component of the work, are by Lakṣmīdāsa (A.D. 1501), Gaṇeśa Daivajña (17th cent.), Nṛsiṃha (1621) and Munīśvara (17th cent.).

In his short work *Siddhānta-darpaṇa*, Nīlakaṇṭha Somayāji (*b*. 1444) sets out the astronomical constants according to the *Āryapakṣa* as corrected by him and also the situation of the armillary sphere. He has also commented on this work in detail. His *Tantrasaṃgraha* in 432 verses, divided into eight chapters, however gives a full treatment of the subject.

A few *siddhāntas*, apocryphal in nature, are available in print. They are: *Vṛddha-vāsiṣṭha-siddhānta* in 13 chapters dealing with all topics of astronomy, *Vāsiṣṭha-siddhānta*,

in 95 verses divided into five chapters, *Soma-siddhānta,* a comprehensive work in ten chapters, and *Brahma-siddhānta,* in 764 verses divided into six chapters which claims to be a part of *Śākalya-saṃhitā.* There is also a *Vyāsa-siddhānta,* in three sections entitled *Bhuvanakośa, Kakṣādhyāya* and *Golādhyāya,* which claims to be part of *Vyāsasmṛti.*

Mention might be made here of a late *siddhānta* work entitled *Siddhānta-sundara* by Jñānarāja who wrote from Pārthapura on the Godāvarī in A.D. 1503. The author claims that Brahmā, Sūrya, Soma, Vasiṣṭha and Pulastya agree with his *Saurapakṣa* parameters. It is again to be noted that by Brahmā he refers to the *Brahma-siddhānta* of the *Śākalya-saṃhitā* noticed above. The work has a commentary by the author's son Cintāmaṇi (*c.* 1530).

Karaṇas

Astronomical computations based on *kalpas* and *yugas* involving large numbers being cumbersome, a genre of practical manuals, called *karaṇas,* arose and was designed to lighten the work of calculations and produce quick and more accurate results. A contemporary date at the sun-rise of which there occurred a conjunction of the Moon and its higher apsis, was chosen as the epoch[21] and the longitudes of the other planets were determined accurately for this moment to be used as zero corrections. Computations were then made with this epoch as the basis. Usually, *bīja* corrections were also applied to the parameters.

The recensions of the *Pauliśa*-and *Romaka-siddhāntas* of Lāṭadeva (6th cent.) pupil of Āryabhaṭa, redacted in the *Pañcasiddhāntikā* of Varāhamihira (d. 587) are the earliest *karaṇa* texts in Indian astronomy. The *Saura-siddhānta* of the *Pañcasiddhāntikā* is also a *karaṇa* text, and according to Al-Bīrūnī this is also a work of Lāṭadeva. The epoch of all these *karaṇas* is 21 March, 505. It is interesting to note that Chapter 4 of his *Pañcasiddhāntikā,* dealing with spherical trigonometry is called *karaṇādhyāya.* Obviously, at that time, the term *karaṇa* meant only 'astronomical calculation' and *siddhāntas* included also *karaṇas.*

The *Khaṇḍakhādyaka* of Brahmagupta, of epoch 23 March 665, bases itself on the *Ārdharātrikapakṣa* of Āryabhaṭa I. The different astronomical topics are dealt with in nine chapters which form Pt. I of the work. In Pt. II corrections are given to the parameters of Part I, changing them to *Brahmapakṣa.* The work had been extremely popular in the whole of North India. It has been commented upon by Pṛthūdakasvāmin (A.D. 864), Bhaṭṭotpala (969), Āmarāja (*c.* 1200), Yamaṭa, Varuṇa and Śrīdatta. A *Khaṇḍakhādyaka-sāraṇī* is also known.

Laghumānasa of Muñjāla (10th cent.) is a *karaṇa* in six chapters using the elements both of the *Āryapakṣa* and the *Ārdharātrikapakṣa* and mentions of the second inequality in lunar motion. The work has been commented by Praśastadhara of Kashmir (A.D. 958), Sūryadeva Yajvan of the Cola country (1248), Parameśvara (1409) of Kerala and Yallaya (1482) from the Telugu country. Muñjāla had composed also a *Bṛhanmānasa,* which is lost and is known only from quotations which give its epoch as 9 March 932; the epoch of the *Laghumānasa* is likely to be the same.

Rājamṛgāṅka of king Bhoja of Dhārā, whose epoch is 21 February 1042, is not available in its original form, but only in three incomplete versions, of which one version by Rāma is available in print.

The *Karaṇaprakāśa* of Brahmadeva is based on the *Āryapakṣa,* and has its epoch on 11 March 1092. This *karaṇa* has been a popular work in south and west India and has commentaries on it by Dāmodara, Amareśa, Govinda, Śrīnivāsa Yavan and Sampatkumāra. Commentator Dāmodara has composed, on his own, two *karaṇa* texts, *Āryatulya* in 1417, based on *Āryapakṣa* and a *Sūryatulya* based on the *Sūrya-siddhānta.*

The *Bhāsvatī* of Śatānanda of Puri, in 8 sections, is a popular *karaṇa* based on the *Sūrya-siddhānta* of Varahamihira's *Pañcasiddhāntikā.* It follows the *Ārdharātrikapakṣa* and has been commented on by nearly 25 scholiasts.

Bhāskara II has written also an erudite *Karaṇakutūhala,* called also *Grahagāma kutūhala* and *Brahmatulya.* This work has been very popular in the west and north-west of India. It has its epoch on 23 February 1183 and follows the *Brahmapakṣa.* Of its several commentaries the more important are those by Ekanātha (1370), Padmanābha (*c.* 1400), by Viśvanātha (1612) and by the Jaina astronomer Sumatiharṣagaṇi (1621). There is also a set of planetary tables based on this work, called *Brahmatulyasāraṇī.*

The *Grahalāghava* or *Siddhānta-rahasya* of the prolific astronomer Gaṇeśa Daivajña in 16 chapters, of epoch 18 March 1520, is a very popular *karaṇa* commented upon by the author himself and by a host of scholiasts. Several planetary tables based on *Grahalāghava* are also known.

Rāmavinoda by Rāma, a courtier of Akbar, belongs to the *Saurapakṣa* and has 11 March 1590 for its epoch. The author himself prepared a *koṣṭhaka* for the work, while there is a commentary on it by Viśvanātha (1602). Still another *karaṇa* following the same *pakṣa* is the *Sūryapakṣaśaraṇa* or *Khacarāgama* of Viṣṇu, having the epoch 7 March 1608, on which Viśvanātha wrote a commentary in 1612.

Koṣṭhakas or Sāraṇis

Alongside the *karaṇas* from about the 10th cent., a genre of ancillary Tables called *koṣṭhakas* or *sāraṇis* came into vogue, in which were charted, in columns, the planetary positions, cusps of the astrological places or other calendrical functions like *tithis, nakṣatras, yogas* etc. Since these tables were extremely handy for almanac-makers, a very large number of *koṣṭhakas* or *sāraṇis* came to be produced, based on different *karaṇas.* In some cases the authors of the *karaṇas* themselves prepared the *sāraṇis.* Every almanac-maker, priest and astrologer had to have his own copy of a *sāraṇi,* with the result that a very large number of manuscripts of this type of works is known.[22]

Diverse texts from Kerala[23]

Astronomical thought in South India, especially in Kerala, developed, from early times, certain features varying from the traditions in the rest of India. For this reason, it would be advantageous to assess, under a separate heading, the contributions of this region in the said aspects. It might be noted at the outset that Kerala had been a strong bastion of the Āryabhaṭan school of astronomy from early times. Numerals in Keralite works are expressed in the *kaṭapavādi* notation, and while the language of most of these works is Sanskrit, their commentaries are mostly in the local Malayalam language.

i. *Parahita and Dṛk Systems of Computation.*

Tradition has it that astronomers of Kerala gathered at Tirunāvāy on the Arabian coast, in A.D. 683 and formally inaugurated the *Parahita* system of astronomical computation with emendations to Āryabhaṭan elements which had till then been followed in the land. The *Grahacāranibandhana* and *Mahāmārganibandhana* of Haridatta formed the basic texts of the system. Several centuries later, when results derived from *Parahita* were found not to tally with observation, Parameśvara (1360-1455) enunciated in 1431 his *Dṛk* system of computation through his *Dṛggaṇita.* While these two basic texts provided only the basic elements and rules, in their wake, a large volume of *karaṇa* literature, treating in detail some or all the topics of astronomy, and introducing further changes, novel methodologies and the like, came to be produced. Shortly after Haridatta, but apparently unconnected with his work, Devācārya wrote in A.D. 689 his *Karaṇaratna,* a full-fledged *karaṇa,* dealing, in eight chapters, all the major topics of practical astronomy, including the determination of the longitudes of the Sun, Moon and planets, the eclipses, gnomon shadow, rising of the Moon, heliacal visibility and planetary conjunctions. Among later texts might be mentioned the *Vākyakaraṇa* (*c.* 1300) to be noticed below, the *Dṛkharaṇa* in 10 chapters of Jyeṣṭhadeva (1500-1610), *Karaṇasāra* by Śaṅkara Vāriyar (1500-60) in 4 chs. with auto-commentary, *Karaṇāmṛta* of Citrabhānu (1530), in 4 chs., having two commentaries, *Karanottama* of Acyuta Piṣāraṭi (1550-1621) in 5 chs., with autocommentary, *Bhadradipagaṇita* of Iṭakramañceri Nampūtiri (17th cent.), *Karaṇapaddhati* of Putumana Somayāji (1660-1740), *Jyotiṣśāstrasaṃgraha* and *Saṃgrahasādhanakriyā* of Āzvāñceri Tamprākkaḷ (18th cent.) and *Sadratnamālā* of Śaṅkara Varman (1800-38). There are at least eleven different texts with the common title *Pañcabodha,* some of them with commentaries, nine texts with the title *Grahagaṇita,* two texts with the title *Kriyāsaṃgraha,* a dozen texts with the title *Vyatipatagaṇita* and several other anonymous texts, often with commentaries.

ii. *Astronomical vākyas.* The *Parahita* and *Dṛk* based systems make use of a large number of mnemonics couched in the form of words, phrases or short sentences (*vākyas*) which, when deciphered in terms of the *kaṭapayādi* system of numeral notation, yield different astronomical tables. These *vākya*-mnemonics relate to all sorts of astronomical tables, to wit, the 248 daily longitudes of the Moon for 9 anomalistic months (well-known as the *Candravākyas* of Vararuci), 3031 daily lunar longitudes for 110 anomalistic months, 2075 *vākyas* called *Samudra-vākyas, Maṇḍala-vākyas.* or *Kujā-*

dipañcagraha-mahāvākyas for the five planets, 570 for Kuja, 528 for Budha, 231 for Guru, 165 for Bhṛgu and 551 for Śani, the different sines of arc *(iyās)*, deductive components to be used in computations and so on and so forth. Some of the *karaṇa* texts make profuse use of these mnemonic-*vākyas*. Following Haridatta's basic *Parahita* manual *Grahacāranibandhana,* the first known major text that makes use of this device is the *Vākya-karaṇa* ('*Karaṇa* utilising *vākyas*') in five chapters, apocryophally attributed to Vararuci, but composed about A.D. 1300. The work has been commented upon in great detail by Sundararāja (*c.* 1500) of Viprasadgrāma near Trichinopoly in Tamilnadu. The almanac-makers of the Tamil region of South India fully make use of the *Vākyakaraṇa* for computing their almanacs, which, therefore, are known as *Vākya-pañcāṅgas.*

iii. *Tantra texts.* Alongside the *karaṇa* texts, which were more in the nature of practical manuals, a genre of texts which aimed to be more comprehensive in the treatment of the topics, besides serving the purpose of the *karaṇas,* came to be produced. These texts followed the *Āryapakṣa,* retained the beginning of Kali, viz. 18 Feb., 3101, as the epoch, and expressed numbers in the *bhūtasaṃkhyā* notation instead of the *kaṭapayādi* notation of the *karaṇas*. To this genre belong the *Vārṣika-tantra* of Viddaṇa, son of Mallaya (before 1370), in 11 chapters, the *Tantrasaṃgraha* of the versatile astronomer Nīlakaṇṭha Somayāji (*b.* 1444) *Sphuṭanirṇaya-Tantra* of Acyuta Pisāraṭi (1550-1621) and the *Tantrasāra* of Nārāyaṇa of the Perumanam village in central Kerala. The last has been commented in Malayalam, but for the second, there are five commentaries including the elaborate *Yuktidīpikā* of Śaṅkara which takes pain to explain the rationale of the theories and the computations.

iv. *Veṇvāroha texts.* Mādhava of Saṅgamagrāma near Cochin (*c.* 1340-1425), whose investigations into the value of π and other trigonometrical functions, differentials in sines of arc etc. are well known, has devised an ingenious method to determine, at intervals of 2 hours and 40 minutes each, every day, the longitude of the Moon correct to the second, utilizing the cyclic nature of the 248 lunar *vākyas* equal to nine anomalistic months. On a parallelism between this method and the knots in a bamboo tree, he called this the *Veṇvāroha* method. For use in this computation, Mādhava also refined the lunar *vākyas* correct to the second. The *Veṇvāroha* method has been set out in two of this works, the *Sphuṭacandrāpti* and *Veṇvāroha*. The ingenuity of this method appealed to other astronomers also and we have several works of the type, including a *Dṛg-veṇvārohakriyā* of epoch 1695, and Putumana Somayāji's *Veṇvārohāṣṭaka.*

v. *Planetary tables.* Besides his work on the moon, Mādhava has worked on planetary motions as well and has determined the longitudes of the planets for long cycles of years and the results have been set out in the form of tables in his *Agaṇita-grahacāra.* Two other anonymous works of a similar nature are also known, both under the common name *Grahacāra,* one of them for the years 1845-55.

vi. *Eclipses.* Investigations on accurate computation of eclipses had the greatest appeal to Kerala astronomers, perhaps, next only to the computation of the planets

This is exemplified also by the series of observations of eclipses made and recorded by astronomers like Parameśvara and Nīlakaṇṭha. A large number of works on eclipse computation, short or long, some of them improvising new or revised elements and methodologies, are known. Among these might be mentioned: The *Grahaṇāṣṭaka* and *Grahaṇamaṇḍala* (epoch 15 July 1411) of Parameśvara, *Grahaṇanirṇaya* of Nīlakaṇṭha (b. 1444), an *Uparāgakriyākrama* based on Nīlakaṇṭha's work, another *Uparāgakriyākrama* by Nārāyaṇa (1561), *Uparāgaviṃśati* and *Uparāgakriyākrama* by Acyuta Piṣāraṭi (1550-1621), and *Grahaṇagaṇita* and *Grahaṇāṣṭaka* by Putumana Somayāji (1660-1740). A number of anonymous works on the subject are known: Two short texts under the name *Grahaṇāṣṭaka* III-IV, another under the title *Uparāgāṣṭaka* (epoch 1563), *a Grahaṇopadeśa,* three texts under the general title *Grahaṇādigaṇita* and then under the title *Grahaṇagaṇita*. Some of these texts have also commentaries, mostly in Malayalam.

vii. *Computation of the Shadow*. Still another genre of texts relate to the computation of the Moon's shadow towards determining the time and therefrom planetary positions. Of this genre of works, the undermentioned are important: *Candracchāyāgaṇita* I of Parameśvara, *Candracchāyāgaṇita* II with a detailed commentary by Nīlakaṇṭha, two more *Candracchāyāgaṇitas* (III-IV), which remain anonymous, and *Chāyāṣṭaka* of Acyuta Piṣāraṭi. Other works on the subject, all anonymous, are *Candracchāyānayanopāvaḥ*, four different tracts of the title *Chāyāgaṇita, Sūryacandracchāyāgaṇita* and two works called *Sūryacchāyādigaṇita*.

viii. *Astronomical rationale*. One of the major hurdles in the study of the history of Indian astronomy lies in the tendency of the early scientists to record the results only of their findings and fail to record, similarly, the steps that led to those results. Apart from their tendency, this was necessitated also by the fact that the results had to be recorded in as succinct a manner as possible, in the form of aphorisms or verses. An understanding of the mental working of the scientists is thus lost of posterity. This defect has been remedied to a great extent, so far as mathematics and astronomy are concerned, through a class of writings called *Yukti-s* ('rationale'). Many of these are short anonymous tracts dealing with individual items, processes or formulae and are found written on flyleaves or ends of manuscripts of astronomical works. From among full-fledged works of this class might be mentioned the *Lagnaprakaraṇa* of Mādhava (1360-1440) on the computation of the ascendant, the *Grahaṇanyāyadīpikā* of Parameśvara on eclipse computation, *Yuktibhāṣā* of Jyeṣṭhadeva, (1500-1610), an extensive work in two parts, depicting the rationales of arithmetic, algebra, geometry and trigonometory in the first part and of astronomy in the second, *Rāśigolasphuṭāniti*, according to Acyuta Pisāraṭi, giving the rationale, at length, for measuring planetary longitudes on the ecliptic, and *Nyāyaratna* of Putumana Somayāji. A fairly long tract explains the rationale of the Āryabhaṭan verses *Kakṣyāpratimaṇḍala* etc. (*Abh Kāla* 17—21). A number of minor tracts on astronomical rationale have been put together in a collection called *Gaṇitayuktayaḥ*. Among Keralite commentaries which afford expository rationale might be mentioned, the *Yuktidīpikā* on Nīlakaṇṭha's *Tantrasaṃgraha* and *Kriyākramakari* on Bhāskara's *Līlāvatī*, both by Śaṅkara (1500-60), and Acyuta Piṣāraṭi's commentary on his own *Karaṇottama*.

ix. *Observation and experimentation.* A unique work in Indian astronomy is the *Jyotirmimāṃsā* of Nīlakaṇṭha, written in 1504, wherein he stresses the importance of astronomical observation, defends the necessity of correcting parameters periodically, on the basis of observation of eclipses, of the Sun, Moon and the planets, comparing the elements of different schools etc. Perhaps, more important is his *Grahaparikṣā-krama* wherein he demonstrates some of the astronomical methods.

Yantras; Astronomical Instruments

Śaṅkaranārāyaṇa (A.D. 869), court-astronomer of King Ravi Varma of Kerala, refers, in his *Laghubhāskarīya-vyākhyā* (3.20), to an observatory in the capital city, fitted with astronomical instruments, but gives no description thereof. While the gnomon *(śaṅku)*, *nāḍikā* (water clock) etc. find mention in the *Śulbasūtras* and the Jaina texts, a sustained description of astronomical instruments occurs, possibly, for the first time in the *Āryabhaṭasiddhānta* of Āryabhaṭa I (*c.* 476). This work of Āryabhaṭa which sets out his *Ārdharātrikapakṣa* is not available, but extracts from it are preserved in later works. Thus, Rāmakṛṣṇa Ārādhya (A.D. 1472), while commenting on the *Yantrādhyāya* of the *Sūrya-siddhānta* (ch. 13) quotes 34 verses on astronomical instruments from the *Āryabhaṭasiddhānta.*[24] Some of these verses are quoted and explained also by other commentators on the *Sūrya-siddhānta* like Mallikārjuna Sūri (A.D. 1178) on verse 7.12, and Tammayajvā (A.D. 1599) on *vv* 13.20-25.[25] Ch. 14 of Varāhamihira's *Pañcasiddhāntikā*, in 29 verses, is devoted to the subject of astronomical instruments, observations etc. Other early and medieval texts which mention the use of or deal with astronomical instruments are: *Mahābhāskarīya* ch. 3 esp. vv. 56-60 and *Laghubhāskarīya*, ch. 3, of Bhāskara I (A.D. 629), ch. 22 of *Brāhma-sphuṭa-siddhānta* of Brahmagupta (b. 598), ch. 21 of *Śiṣyadhīvṛddhida-tantra* of Lalla (8th cent.), ch. 13 of the *Sūrya-siddhānta* (*c.* 800) *Golādhyāya* of *Vaṭeśvara-siddhānta* (904) ch. 11 of Pt. II of of the *Siddhānta-śekhara* of Śrīpati (*c.* 1050) and ch. 19 of the *Siddhānta-śiromaṇi* of Bhāskara II (1150).

The works on astronomical instruments written later generally bear the impress of Central Asian astronomy brought to India by the Muslims, which will be noticed in the next section. There are, however, a few which treat only of Hindu instruments, mostly written in Gujarat or Rajasthan. Among these might be mentioned the following: The *Yantraratnāvali* of Padmanābha (*c.* 1400), with a commentary by the author himself. The second chapter of this work, called *Dhruvabhramaṇādhikāra* describes an instrument for ascertaining the exact time at night from the position of the pole star. Cakradhara, son of Varuṇa wrote a short work entitled *Yantracintāmaṇi*, of which four commentaries are available, one by the author himself and the others by Harisaṅkara, Paramasukha and Rāma Daivajña (1625).[26] The prolific Gaṇeśa Daivajña, son of Keśava Daivajña of Nandigrāma (1507), wrote two works on instruments, entitled *Cābukayantra* and *Pratodayantra*. An extensive work on the subject is the *Yantraprakāśa* of Rāmacandra with autocommentary, which describes as many as 27 instruments, including a *Kācaghaṭīyantra*. The texts of this genre are short and a close reading of the commentaries are always necessary to get a full idea of the form, nature and use of the instruments of the Hindu period.

ARABIC AND PERSIAN SOURCES

While the peoples of India and Iran belonged to the same Aryan stock and their religion, literature and culture had close relationship from very early times, it was only from the eighth century that scientific exchanges between India and central and west Asia took positive shape due largely to the rise of Islam. The reign of the second Abbāsid Caliph al-Mansūr (A.D. 753-74) heralded an era when considerable Indian scientific literature, especially on medicine and mathematics, including astronomy, were redacted into Arabic. The services of Indian scholars who had mastered Arabic helped in this exchange and among Arabic scholars, the names of Ibrāhīm al-Fazārī (*d.* 796 or 806), Ya'qūb ibn Ṭāriq, al-Khwārizmī (d. *c.*850), al-Kindī (d. *c.*873), Habash al-Hāṣib (d. *c.*864 or 874) are noteworthy. Many of these Arabic translations are lost, but the details thereof are preserved in the *Fihrist* or 'Index' of Abu'l--Faraj Mahammad of Baghdad, better known as Abi Ya'qūb an-Nadim (A.D. 988). Details about scholars of science and their contributions occur in Sn. II of the *Fihrist*.

Al-Birūni

A potential source of information about Indian and Perso-Arabic literature on astronomy and allied disciplines is the large quantum of writings left by Abdu'l-Raiḥān al-Bīrūnī (973-1050), who accompanied Sultan Maḥmūd of Ghazna during his campaigns and stayed in north-west India for the best part of 2027-30. A versatile scholar of Persian and Arabic, and also of Sanskrit, al-Bīrunī, wrote 183 works, comprising of studies, collections and translations, of which as many as 27 pertain to Indian culture, philosophies and sciences.[27] His work entitled *Kitāb fi taḥqiq mā lil-Hind min maqālatin maqbūlatin fi'l-aql au mardhūla* ('Verification of what is said about India which is accepted or rejected by reason'), *Ta'rīq al-Hind,* in short, translated into English under the title *Al-Bīrūnī's India* by Edward Sachau, is well known for the comprehensive information it supplies on contemporary India.[28] Valuable information on Indian astronomy and mathematics is contained in his undermentioned works: *Jawāmi al-Maujūd li-Khawāṭir al-Hanūd fi Ḥisāb al-Tanjim* ('Collection of the ideas of the Indians on astronomical calculations'),[29] *Al-jawābāt 'an al-masā'il al-wārida min munajjim 'l-Hind* ('Replies to questions raised by Indian astronomers'), *Al-Qānūn al-Mas'ūdi* (Book on astronomy).[30] It is worth noting that al-Bīrūnī endeavoured to transmit to Western Asia the knowledge contained in Sanskrit astronomical texts through translations into Arabic or Persian. Such texts included Brahmagupta's *Brāhmasphuṭa-siddhānta* and *Khaṇḍakhādyaka, Pauliśa-siddhānta,* Varāhamihira's *Laghujātaka* and *Bṛhatsaṃhitā,* and *Karaṇatilaka* of Vijayanandi. The worth of al-Bīrūnī's writings lies in the fact that, apart from the intrinsic value of their contents, they provide new information, corroborative evidence and help in the identification and dating of authors, works and views.

Encyclopaedias

Another authentic source of contemporary information is the *Ā'in-i-Akbari,* the Imperial Gazetteer of the times of the Mughal emperor Akbar, prepared by his

minister Abu'l-Faḍl (1551-1602). The work carries details on a variety of subjects, including an account of Indian and Arabic astronomy.

The influx of scholars from the Middle East to India and the patronage extended to them by Muslim rulers, not only in Delhi but also in the provinces, resulted in the production of a number of encyclopaedic works containing, among other things, substantial information of astronomy in its several aspects.[31] Among them the following deserve mention for the wealth of details contained therein: *Jawāharu'l-'Ulūmi-Humāyūn* composed by M. Fādil b.'Ali B.M. al-Miskīnī al-Qaḍi Samarqandī of the court of the Mughal emperor Humayun in 1555.[32], *'Uqūl-i 'Asharah* by M. Barārī Ummī b. Jamshīd (A.D. 1673),[33] and *Shahid-Ṣadiq* by Ṣādiq B.M. Ṣāliḥ al-Isfahānī al-Azadānī (A.D. 1646), of the court of emperor Shahjehan.[34]

Zīj (Astronomical Tables)

The genre of astronomical tables indicating planetary positions, star charts and conversion tables with notes and explanations, on lines with the famous *Zīj-iUlugh Beg* and *Zīj-i Khāqānī* of Samarqand came to be produced, generally under state patronage,[35] like *Zīj-i Nāsiri* (13th cent.) by Mahmud b. 'Umar dedicated to Sultan Iltutmish[36] (1246-65), *Zīj-i Jāmi'* (1448-61) by Maḥmūd Shāh Khaljī[37] and *Zīj-i Shahjaḥani*[38] by Faridu'd-din Mas'ud b. Hafiz Ibrahim Manajjm, Court astronomer of emperor Shahjehan (1628-58). More important, however, is the highly elaborate *Zīj-i Muḥamad Shāhi*[39] (1727) prepared by Sawai Jaisingh, (1686-1743), dedicated to the Mughal emperor Muhammad Shah (1719-48). Divided into three sections, the work gives rules for the transformation of four calendars, measurement of time in 19 chapters, and motions of stars and planets and their position from a certain longitude, latitude etc. in five chapters. That this work was later revised as *Zīj-i Jadid Muḥammad Shāhī* (New Astronomical tables of Muhammad Shahi) in four chapters would indicate how matters were developed further. It is interesting to note a Sanskrit version of this *Zīj* had also been prepared for the use of Hindu astronomers. The Arabic and Persian Zījes studied and produced in India will be further discussed in chapter 2.

Mingling of Traditions

In the wake of the introduction of Arabic and Persian astronomical tradition into India under State patronage, there arose an effort, on the part of Hindu astronomers, to produce translations, adaptations and books of a combined tradition, the combination taking mostly the form of mere addition, explanation of one through the other, or regular coalescence. Obviously, such activities too were encouraged and patronized by the State. Such study, required bilingual dictionaries. Thus Kṛṣṇadasa, a protege of Akbar compiled a *Pārasīprakāśa* in about 1575, containing a Persian-Sanskrit dictionary of astronomical terms and a grammar of Persian in Sanskrit. Since this was inadequate for translators, Mālajit, who was honoured by Shahjehan with the title *Vedāṅgarāva,* wrote another *Pārasiprakāśa* in 1643, which gave classified lists of astronomical terms in Arabic and Persian with Sanskrit equivalents. Vrajabhūṣaṇa, son of Raghunātha, wrote in 1660 still another work of this nature entitled *Pārasīvinoda* or *Pārasīvinodānanda.*

In line with translating of Sanskrit texts into Arabic and Persian by Al-Bīrūnī and earlier in Baghdad,[40] there had also been sustained efforts to translate Arabic and Persian texts into Sanskrit. These texts included those belonging to the school of Marāgha and Samarqand, like the *Ẓij* of Ulugh Beg in *Ji ca Ulugbegi,* and al-Qushiji's *Risalah dar hay'at* in *Hayatagrantha.* In this vein, under the patronage of Sawai Jai Singh, Jagannātha, Paṇḍita produced *Rekhāgaṇita,* being a rendering of Euclid's *Elements of Geometry* from its Arabic version *Tahirir-u-Uqlidas* by Naṣīr-ud-din aṭ-Ṭūsī (1201) and *Siddhāntasārakaustubha* in 13 chapters, being a rendering of Ptolemy's *Almagest* from its Arabic version, also by Naṣīr-ud-din. It is worth noting here that, as against what is presumed by scholars all along, Jagannātha's *Samrāṭ-siddhānta* is really the title of an original work of the author, in five chapters, all along called *Yantrādhyāya,* and printed in continuation of the first 13 chapters, and these 13 chapters alone form the translation of the *Almagest* under the title *Siddhāntasāra-kaustubha.*[41] Nayanasukhopādhyāya produced, under Jai Singh's inspiration, the *Ukarā,* being a Sanskrit rendering of the Greek work *Sphaerica* of Theodosius from its Arabic rendering by Qusta bin Luqa (912 A.D.). Nayanasukhopādhyāya translated into Sanskrit also of another work *Sharah-Tazkarah Barjandi.*[42]

As instances of incorporating Western ideas into India might be cited the *Siddhāntasāryabhauma* of Munīśvara (*b.* 1603), court astronomer of Shahjehan (1628-59), and Kamalākara who wrote the *Siddhāntattvaviveka* in 1658. These astronomers composed their works in the Hindu pattern, but used therein elements of Aristotelian physics, Euclidean geometry, Islamic trigonometry and Ptolemaic astronomy as found in Ulug Beg. Among works which tried to coalesce the two traditions might be mentioned the *Siddhāntasindhu* (1628) and the *Siddhāntarāja* (1639) of Nityānanda, astronomer in the court of Shahjehan, which adopted the Islamic parameters and the *sāyana* year in computation. These innovations, however, remained confined to intellectual experimentations and did not permeate into general use among the people.

ASTROLABES AND OBSERVATORIES

With Arabic astronomy came the astrolabe (Arabic *aṣṭurlab,* Sanskritized into *ustaralava*), a handy and versatile metallic instrument, which, through the manipulation of graduated discs and circles and of a gnomon attached to it, enabled one to ascertain planetary positions, the time of the day and the like. Being a complicated precesion instrument, it used to be prepared by hereditary families of experts, with graduations and words inscribed in Persian script. As the instrument grew popular in the land, it began to be inscribed in Devanagari script, as well. Short works in Sanskrit also came to be composed describing the construction and use of astrolabes. The earliest work on the astrolabe is the *Yantrarāja* (1370), mentioned earlier based on Arabic sources, by the Jain Mahendrasūri, court astronomer of Ferozeshah Tughlaq, in five chapters entitled *Gaṇita, Ghaṭanā, Yantraracanā, Yantraśodhana* and *Vicāraṇā.* There are commentaries on the work by Malayendasūri and Gopirāja.

Other works on the subject, of a later period include those of Malayendu (with Cintāmaṇi's commentary) and by Mathurānātha and some anonymous, but by far

the most important is the *Yantrarājaracanā* by the royal astronomer Sawai Jai Singh and its rendering into verse form by Śrīnatha under the title *Yantraprabhā,* over which its modern editor Kedaranatha has added his own commentary, *Yantrarāja-prabhā.* A number of Indian astrolabes, of different types, combinations and functions, are preserved in museums and other repositories[43] and await detailed study.

The efforts of the Raja Sawai Jai Singh of Jaipur (1686-1743) towards the fostering of scientific observational practices with the combined use of Hindu, Muslim and European advances in astronomy are a saga in itself in the history of Indian astronomy. Jai Singh collected texts of all the three traditions, studied them himself and composed works, invited scholars of all the traditions and induced them to prepare original works and translations. He also invented and caused to be constructed instruments for astronomical observations. A manuscript entitled *Yantraprakāra,* preserved in the Art Gallery as No. 31 of the Maharaja's Museum at Jaipur, mentions the undermentioned instruments as designed by Jai Singh with the caption: *Śrī-Mahārājādhirāja-viracita-yantrāṇi:* (1) *Jayaprakāśa-yantra,* (2) *Nāḍīvalaya,* (3) *Krāntivṛttam,* (4) *Palabhāyantram,* (5) *Digaṃśayantram,* (6) *Śarayantram,* (7) *Agra-yantram,* (8) *Yāmyottaramiti,* (9) *Jatulahalaka,* (10) *Yantrarāja* (astrolabe, mentioned above), (11) *Jātuśukavataina,* (12) *Sudasphakari,* (13) *Jātuśukataina,* (14) *Śaṅkuyantra* and (15) *Pratirāśīnām Krāntivṛttāni.*[44] The main features and methods of observation of some of these instruments have been indicated by Jagannātha in the first chapter of his *Samrāṭsiddhānta.*

Three instruments, viz. *Jayaprakāśayantra, Rāmayantra* and *Samrāṭ-yantra* are stated to have been invented by him. Realising, by experience, that these metallic instruments suffered from limitations on account of their smallness, wear and tear, and the effect of weather, he constructed massive outdoor observatories, like those of Ulug Beg in Samarqand, in Delhi (1724), Jaipur (1734), Ujjain (1734), Varanasi (1737) and at Mathura on the Yamuna. Massive models of several of the instruments were also installed by him at these observatories.[45] The contribution made by Jai Singh and that inspired by him form a potential source for the study of a special phase of the history of Indian astronomy.

2 DEVELOPMENT OF ZĪJ LITERATURE IN INDIA

S. A. KHAN GHORI

Muslim astronomy, or to be more precise, Graeco-Arabic astronomy in Medieval India had its origin in West-Central Asia whence it passed to this country. Valuable contributions were made to it by Arabic and Persian knowing scholars. Hence in order to evaluate these contributions it is essential to know the nature, origin and development of this system, to examine important zījes prepared in West-Central Asia and to understand how they influenced the preparation of their counterparts in India.

GRAECO-ARABIC ASTRONOMY

Nature of Graeco-Arabic Astronomy

Graeco-Arabic astronomy is geo-centric. The earth, a tiny point in comparision with the vast dimensions of the universe is at its centre. The universe consists of thirteen concentric spheres, four terresterial and the remaining nine celestial.[1] Of the latter each of the seven lower ones are made up of a number of components called eccentrics and epicycles.[2] The eccentrics revolve with uniform circular velocity round different centres, not coincident with that of the universe. Each of the seven planets with the exception of the Sun is studied within an epicycle, which in its turn is fixed in the eccentric and the latter in the main sphere called "*al-Mumaththal*". The sum total of the motions of the *mumaththal* together with those of the eccentric and epicycle determines the apparent motion of that planet. The next outer or the eighth sphere is studied with fixed stars and is called *Falak-uth-thawābit*. The ninth or the outermost sphere is called *Falak-ul-Aflāk* and was assumed to rotate on its axis in about 24 hours. This rotation causes the succession of day and night.[3]

Origin and Development of Graeco-Arabic astronomy in West Asia

Foundation of Muslim astronomy was laid in the very beginning of Islam, which enjoined upon its followers a meaningful observation of celestial phenomena.[4] Astronomy proper started from the reign of second Abbasid Caliph al-Manṣūr[5] (A.D. 753-774) when the *Almagest*[6] and the *Brāhmasphuṭa-Siddhānta* were translated into Arabic. The scientific movement[7] started by Al-Manṣūr reached its climax in reign of his great grandson Al-Māmūn[8] (A.D. 813-833) who built the two observatories at Baghdad and Damascus.[9] The movement continued after him as well. Great astronomers like the sons of Musā bin Shākir, Habash the computer, Al-Kindī, al-Mahānī, Al-Narauzī, Thābit bin Qurra, Sulaymān bin 'Iṣma, to name only a few, flourished after Al-Māmūn. But more renowned than the rest was Albatignius, the illustrious author of *Az-zīj aṣ-Ṣābi*.

The tenth century A.D. was the golden period of Muslim astronomy. The Balkanization of the Muslim world provided a new momentum to the progress of astronomy, as different rulers vied with one another in the patronage of science and scientists. It was the age of great astronomers such as Abū Ja'far al-Khāzin in Khurāsān, Ibn ul-A'lam, 'Abdur Raḥmān-aṣ-Sūfī, and Aḥmad bin 'Abdul Jalīl as-Sijzī in Shīrāz (the last named advocated the helio-centric theory), Abul-Wafā' al-Buzjānī at Baghdad, al-Khujandī, the inventor of *Fakhri* sextant at Raj and Abū Naṣr bin Iraq (the teacher of al-Bīrūnī and the discoverer of sine theorem of plane and spherical trigonometry in Khwārazm).

The later half of the tenth and the first half of the eleventh century produced four eminent astronomers of exceptionally high calibre: Avicenna and Al-Bīrūnī in the east, and Ibnul-Haytham.[11] and Ibn Yūnus in the west (Egypt). It was in the beginning of the eleventh century that al-Bīrūnī was exiled into India and introduced the study of Graeco-Arabic astronomy in this country.[12]

In the later half of the eleventh century, the Saljūq Sulṭān Malik Shāh built an observatory to determine the true time of vernal equinox[13] and to reform the calendar, and introduced the *Maliki Era.*

The twelfth century produced a good number of important astronomical works such as Al-Khurqi's *Muntah al-idrāk* and *At-tabṣira,* Al-Khāzinī's *Ẓij-i Sanjari* and Chaghmīnī's *al-Mulakhkhaṣ fil-Hay'at.*[14]

Then came the eruption of Tartar marauders who in the middle of the thirteenth century devasted Central and Western Asia. But even this unprecedented calamity could not interrupt the progress of astronomy. Under Halākū, Naṣīrud-Dīn Tūsī built the famous Marāgha Observatory[15] and wrote *Tadhkira* and *Ẓij-i Īlkhānī,*[16] which served as a model for subsequent zījes. His pupil composed two important astronomical works *Nihāyat ul-idrāk* and *Tuḥfa-i Shahiya.* He also wrote an encyclopaedia, *Durrat-ut-tāj.*[17] In the following century good commentaries were written on astronomical texts such as "Chaghmīnī's *al-Mulakhkhaṣ fil-Hay'at* and Ṭūsī's *Tadhkira and Ẓij-i Īlkhānī*[18].

Development of Graeco-Arabic astronomy in Central Asia

In the latter half of the fourteenth century the centre of scientific activities shifted to Central Asia. Tīmūr, besides being a famous conqueror, was also a great patron of science and letters[19] and this tradition also continued in his dynasty. His grandson Ulugh Beg was himself a great scholar of mathematical sciences.[20] He founded the first academy of science of modern times. The four members of this academy were Qāḍī Zādeh Rūmī (the commentator of Chaghmīnī's *al-Mulakhkhaṣ fil-Hay'at,* Ghaiyāth ud-Dīn Jamshed Kāshī (the author of *Ẓij-i Khāqānī*), Mu'īn-ud-dīn Kāshī and 'Alā uddīn Qaushjī[21] (the de-facto author of *Ẓij-i Ulugh Beg*). The king also erected an observatory at Samarqand (A.D. 1420) under the directorship of Qāḍī Zādeh and Jamshed Kāshī, and after their death, under that of Qaushjī.[22] The findings of the observatory were compiled by the king with the help of Qaushjī in what was subsequently called *Ẓij-i Ulugh Beg.*[23] After Ulugh Beg and Qaushjī, the centre of astronomy was shifted to India.

ZĪJES PREPARED IN WEST-CENTRAL ASIA

PRE-TARTAR ZIJES

Nature of a Zīj :—

A *zīj* is a set of a number of astronomical tables prepared directly or indirectly on the basis of the findings of a particular observatory.

In Indian literature the term *zīj* seems to have been explained first by Abul Faḍl in his *Āin-i Akbarī* and later on by Mullā Farīd, the court astronomer of Emperor Shāhjahān in his astronomical work *Sirāj ul-Istikhrāj* and *Zīj-i Shāhjahānī.*[25] As Mullā Farīd was himself the author of an important *zīj*, his description is to be preferred. He prefaces his description with that of an observatory (in Arabic Raṣad) and says :

> "Raṣad means the observation of different celestial bodies with the help of instruments specifically manufactured for that purpose and to determine with their help, the positions of the stars in the sky (i.e. their longitudes and latitudes), to measure their movements, their distances from one another and from the earth, their sizes and such other conditions. When the movements of the stars have been determined, in accordance with the set principles of astronomical observations, they are carefully entered in a register. And that register is called a *Zīj.*[26]

Then he divides the *zījes* into two classes :

(i) *Zīj-i Raṣadī* or observational tables which are prepared directly from the findings of an observatory, such as *Zīj-i Ulugh Beg* compiled directly at Ulugh Beg's observatory in Samarqand.

(ii) *Zīj-i Ḥisābī* or computational tables. As it is not easy to build an observatory which entails tremendous cost and requires highly sophisticated instruments, generally later astronomers brought up-to-date the parameters of a previously compiled *Zīj-i raṣadī.* Such tables are called *Zīj-i-Ḥisābī.* The est bexample of this class is *Zīj-i Shāh-Jahānī* which is essentially an up-to-date revision of *Zīj-i Ulugh Beg.*[27] Major portion of *zīj* literature in Arabic and Persian comes under the class *Zīj-i Hisābī.*

Important zījes before Al-Birūnī :

The first ever *zīj* among Muslim astronomers was prepared by Al-Fazārī, the court astronomer of Caliph Al-Manṣūr (A.D. 753-774) under his command.[28] It was based upon *Brāhmasphuṭa-Siddhānta,* though the years employed in its computation were the Arabian (Ḥijrī years).

Al-Fazārī's colleague Y'aqūb bin Ṭāriq who was also impressed by a member the Indian astronomical mission wrote another *zij* entitled *az-Ẓij-al-Maḥlūl min-as Sindhind* (Astronomical Table solved with the help of *Siddhānta*).[29]

Some twenty years later an observational table entitled *az-Ẓij al-Mushtamil* was compiled by Aḥmad Bin Muḥammad an-Nahāwandī, the Director of the observatory at Jundisāpūr[30] (c. 741 A.H.).

Then came Al-Māmūn (A.D. 813-833) who as stated before built the Baghdad and Damascus observatories.[31] The participants especially 'Abbās bin Sa'īd al-Joharī and Sanad bin 'Alī prepared their own (private) tables. But officially the record was entered in what was called *Az-Ẓij Al-Mumtaḥan* (the Tested Tables), the authorship of which is generally attributed to Yaḥyā bin 'Alī Manṣūr, the chief astronomer of Māmūn.[32]

But more important than these tables was the one by Muḥammad bin Mūsā Al-Khwārazmī. In this *zīj* were fused the three astronomical systems, the Greek *Almagest*, the Persian *Ẓij-i Shahriyār* and the Indian *Siddhānta*.[33]

The movement started by Al-Māmūn continued after his death as well. Two astronomers of exceptional calibre flourished among his successors :—

Aḥmad bin 'Abdullāh, also called Ḥabash-Al Ḥasīb composed three *Ẓijes* :— *Ẓij-as Sindhind* based on Indian Siddhānta; a revised edition of Al-Māmūn's *Az-Ẓij-al-Mumtaḥan* and a small table called *Ẓij-ash-Shāh* (very probably based on *Ẓij-i Shahriyār*.[34]

The other were the Banū Mūsā (the sons of Mūsā bin Shākir, the astronomer). They built their own observatory, the findings of which they entered in a book entitled *Sanat ush-Shams* (solar year) also ascribed to Thābit bin Qurrah.

In order to highlight the continuity of astronomical activities in Islam, a few very important zījes are mentioned below :

Chief among them was Al-Battānī's *Az-Ẓij-as-Sābi* which he compiled from the findings of his own observations extending from A.D. 877 to 918.[35] About this *zij* Ibn-ul Qifṭī says, "I know no one among Muslim astronomers", who reached the intellectual status of this savant.[36] Consequently great number of *Ḥisābi Ẓijes* (Computational Tables) were based upon Al-Battānī's Tables.

Another important *zīj* was prepared by Al-Battānī's contemporary Faḍl bin Ḥātim an-Narayzi and dedicated to the Caliph al-M'utaḍid (A.D. 892-901). Hence it is called *Az-Ẓij Al-M'utaḍidī*.[37]

Among the later contemporaries of Al-Battānī was the family of Banī Amājūr. The members of the family made astronomical observations with which they composed twelve *zījes*.

The golden period of Islamic astronomy commenced with the political ascendancy of the Buwayhids. The encouragement the new dynasty gave to astronomy resulted in the writing of a number of standard works, including *zījes* such as :

1. *Zīj-As-Safāih* of Abu J'afar al-Khāzin;[38]
2. *Al-Majisṭī* of Abul-Wafā al-Buzjānī;[39]
3. *Al-Majisṭī-ash-Shāhī* of Abū Naṣr bin Irāq, the teacher and patron of Al-Bīrūnī;[40]
4. *Zīj-i Ibn-ul-A'lam,* which was perhaps the best contribution of this period,[41] as it was relied upon by Naṣiruddīn al-Ṭūsī in the compilation of his Īlkhānic Tables.[42]

Astronomical works of Al-Birūnī

Al-Bīrūnī was a versatile and prolific writer who composed a great number of books on astronomy and allied subjects. But the work that has immortalized him in the history of astronomy is his *Qānūn- al-Mas'ūdī*[43] (Canon Masudicus) also called *Zīj-i Mas'ūdī.* Like Ptolemy's *Almagest,* it is also divided into thirteen books *(maqālas).* He also wrote commentaries on al-Khwārazmī's "Tables".[44] In some of them he defended him against the criticism of his adversaries.

Zījes written after Al-Birūnī

After Al-Bīrūnī's *Qānūn al-Mas'ūdī* the best *zīj* was written by his contemporary Ibn Yūnus called *Az-Zīj al-Kābir al-Ḥakimī* as the author dedicated it to the Fātmid Caliph of Egypt Al-Ḥakīm Billāh (d. A.D. 1020).[45] Its importance lies in that it was one of the two *zījes* Ṭūsī relied upon in the computation of his *Zīj-i Īlkhānī.*[46]

A period of lull followed Al-Bīrūnī's death. But it was not altogether barren. Malik Shāh of Saljūkī dynasty built an observatory under the directorship of the famous poet-astronomer 'Umar al-Khayyām.[47] Its findings were recorded in a book called by Abul Faḍl as *Zīj-i Khayyām.*

Another important *zīj* was composed during the later part of Saljūkī rule. It was written by 'Abdur Raḥmān-al-Khāzin and was dedicated to the reigning Sultan Sanjar. Hence its name *Zīj-i Sanjarī.*[48]

POST TARTAR ZĪJES

With the Tartar occupation of middle East, there commenced a new period of Islamic astronomy that inaugurated a new phase of *zīj* literature. Hitherto the bifurcation between an astronomical Text and astronomical table was not clearly defined. Moreover, major portion of a *zīj* was devoted to the description of astronomical principles and comparatively less space was given to tables. For instance, *Az-Zīj-as-Sabi* consists of fifty-seven chapters, greater number of which are on the demonstration of astronomical principles. Similar is the case with *Zīj Ibn Yūnus* and *al-Qānūn al-Mas'ūdī* or *(Zīj-i Mas'ūdī).*

Of the many *zijes* prepared in this period, three are most important, as they exercised an enduring influence on the preparation of subsequent *zijes*, especially in India. They are *Zij-i Īlkhānī*, *Zij-i Khāqānī* and *Zij-i Ulugh Beg.*

Zij-i Īlkhānī. It was an observatorial *zij*, prepared on the basis of the observations made in Marāgha observatory. This observatory was built by Halakū Khān, the Īlkhānī ruler of Irān on the advice and directorship of Khwāja Naṣīruddīn at-Ṭūsī in A.D.1258. It was built in Marāgha near Tabrīz. Besides the Director Naṣīruddīn Ṭūsī, four other eminent scholars were also invited to participate in the working of the observatory. They are, as given by Ṭūsī in the preface of this *zij*, Fakhruddīn of Marāgha, Mu'yyad uddīn al-'Urḍī from Damascus, Fakhruddīn of Akhlāṭ from Tiflis and Najmuddīn Dabīrān from Qazwīn.[49]

Though the working of an observatory takes at least thirty years, but as Halākū Khān was making haste, the work was finished in about twelve years. The results were recorded in this *Zij* in A.D. 1271. And as by this time Halākū had died, it was dedicated to his son and successor Abā Qa'ānī.[50]

Zij-i-Īlkhānī started a new pattern. The whole content of astronomical topics was divided into three parts, chronology, spherical trigonometry and astronomy and planetary motions. Hence this *zij* consists of three *maqālas* (of astronomical importance), namely, (i) On different eras, (ii) The movements of the stars and their positions (longitude and latitude); and (iii) Determination of the time of ascendents.

To these three *maqālas* was added a fourth on astrological predictions. This arrangement was followed by subsequent writers of *zijes* (except by Jamshed Kāshī). Every *maqāla* is followed by a number of tables.

Zij-i Khāqānī. This *zij* was prepared by Ghyāthud-dīn Jamshīd of Kāshān. He found some defects in Ṭūsī's Īlkhānic Tables and he set to amend them. He gives a list of about fifty improvements made by him on *Zij-i Īlkhānī* of Ṭūsī. Hence its name *Az-Zij al-Khāqānī Il Takmīl iz-zij il-Īlkhānī.* He started to write this *zij* in A.D. 1374[51] while he was in his native town of Kāshān. Then he was invited by Ulugh Beg to participate in his constituted Academy at Samarqand.[52] There he completed this *zij* in 1413 and dedicated it to Ulugh Beg.[3]

Zij-i Khāqānī consists of the following six *maqālas:* eras; trigonometry and allied subjects; positions of the stars (their longitudes and latitudes; important arts; determining the ascendent from different data, and miscellaneous astronomical and astrological topics.

MS copies of this *zij* are very rare. The cataloguer of India Office Library says that the unique copy of this *zij* is there in the Library. But another copy seems to exist in Central Library, Hyderabad.[54] Rājā Jai Singh Sawāi, the builder of Delhi

Observatory and the author of *Zīj-i Muhammad Shāhī* had a copy of this *Zīj* and had studied it. It is extant in his library.

Zīj-i Jadīd-i Sulṭānī. This is the famous *zīj* of Ulugh Beg. He was very much interested in intellectual sciences, especially in mathematics, and wanted to build an observatory in order to perpetuate his name.[55] He translated his project into practice in 1420. A suitable site for this purpose was selected near Samarqand, and necessary instruments and equipments were procured and the observatory began to work,[56] first under the supervision of his teacher (in mathematics) Qāḍī Zādeh Rūmī and Maulānā Ghiyāth-uddīn al-Kāshī. But before any tangible result could be found, both the directors died one after the other. The work then was entrusted to Maulānā 'Alāuddīn al-Qaushjī, who was Ulugh Beg's pupil in mathematics. Qaushjī under the overall supervision of Ulugh Beg carried out the project and compiled the *Zīj* in A.D. 1438. This *zīj*, like Īlkhānī Tables, is also divided into four *maqālas*, e.g. eras, the motions of the stars and their longitudes and latitudes, determining the ascendent from given data, and astrological prediction.

No important *zīj* seems to have been prepared after Ulugh Beg's *zīj* in Iran or Central Asia. Some zījes were prepared in West Asia, but they did not influence the *zīj* literature of India.

WEST-CENTRAL ASIAN ZĪJES IN INDIA

In Pre-Mughal Times

The earliest reference to *zījes* composed in West-Central Asia is met with during the reign of later Ghaznavids when the poetscribe Mas'ūd S'ad Salmān, while writing an ode in praise of the heir-apparent 'Abul Qāsim Maḥmūd, predicted his glorious coronation. This prediction was based on the data provided by the astronomical tables, *Zīj-i Battānī* and *Kitāb-ut-Tafhīm* of Al-Bīrūnī.[58]

The former has already been referred to. The latter is not a *zīj* in the technical sense of the term, but a compendium of mathematical and astronomical sciences. Still it contains a number of tables, e.g. the gazetteer and the star catalogue.

Zījes enumerated by Abul Faḍl in Ā'īn-i Akbarī.

Abdul Faḍl apparently possessed a great interest in astronomy and consequently, after describing the meaning of *raṣad*, gave a long list of 86 *zījes* in his *Ā'īn-i Akbarī*.[59] But unfortunately this list is not arranged chronologically, nor scientifically. This list shows that scholarly circles in Akbar's time was acquainted with a large number of Islamic *zījes*. These *zījes* are listed in Appendix A.

Zījes listed by Mullā Farīd

In the regin of Akbar's grandson Shahjahān, Mullā Farīd, the court astronomer prepared his astronomical table entitled *Kārnāma-i Sāḥil Qirānī, Zīj-i Shāhjahānī*. In this *zīj*, like Abul Faḍl, he first describes what is meant by a *raṣad* (observatory)

and a *zij*. Then he classifies the latter into *Zīj-i Raṣadī* (Observational Tables) and *Zīj-i Ḥisābī* (Computational Table). Among the former class he typifies *Zīj-i Ulugh Beg* (which he calls *Zīj-i Samarqandī*). Another example of this class is *Zīj-i Battānī.*[60] Among the later class he mentions his own table as a typical example. The list of *zijes* given by Mullā Farīd is listed in Appendix B.

Zījes studied by Rājā Jai Singh Sawāi

Sawāi Rājā Jai Singh in order to correctly determine the exact time of performing religious rites was obliged to study the current astronomical works, written by Hindu as well as Muslim and European astronomers. Among the works written by Muslims, he mentions the following: *Zīj Jadīd Sa'id Gurjānī* (i.e. *Zīj-i Ulugh Beg*), *Khāqānī (Zīj-i Khāqānī of Jamshed Kāshi)*, *Tashīlāt-i Mullā Chānd Akbar Shāhī (Tashīl Zīj-i Ulugh Begi of Mullā Chānd)* and *Mullā Farīd Shāhjahānī (Zīj-i Shāhjahānī)*. Of these the first two had been compiled outside India (already dealt above), whereas the last two were prepared in India (see below).

ZĪJES COMPILED IN MEDIEVAL INDIA

Beginning and Progress of Astronomical Studies in Muslim India

Beginning of Graeco-Arabic Astronomy in India

Astronomical studies in Muslim India started from eleventh century when the celebrated Al-Bīrūnī exiled from his native country[62] continued his investigations in the North-Western part of the sub-continent. Besides learning indigenous sciences he determined the latitudes of some of the cities[63] of the region and what is more important tried to measure the length of one degree of the meridian and thereby determined the length of earth's circumference.[64]

The process of assimilation of West-Central Asian learning was continued by the Indian scribe class. For example, the poet-scribe Mas'ūd Sa'd Salmān learnt astronomy from an old companion of his, named Bahramī, and soon acquired proficiency in this science.[65]

Astronomy during Delhi Sultanate

(i) *Mamlūk rule*. The scribe class was generally conversant with mathematical sciences including astronomy as is evident from an ode of Amīr Khusro which he composed in praise of his teacher Shahāb Mahmara. Amīr Khusro was himself well-acquainted with astronomy especially with the science of fixed stars. He composed a poem on "Twenty-eight lunar Mansions",[66] called *(al-Manāzil)*. It was during this period that the first *zīj* in India was prepared (see below).

(ii) *Khilji* rule. Astrology (and for that reason astronomy) reached its climax in the reign of 'Alā uddīn Khiljī when there was an ever increasing demand for astrologers.[67] Some of these astrologer-astronomers had acquired such proficiency in their subjects that they could construct astronomical observatories.[68]

(iii) *Tughlaq rule.* Among the Tughlaq rulers, Fīroz Shāh Tughlaq was highly skilled in astronomy especially in astrolabe making. He effected important improvements in the construction and designs of astrolabes.[69] The extraordinary interest taken by the ruler in the theory and construction of astrolabes did not leave the subjects (not only Muslim, but Hindu as well) uninfluenced. The first treatise on astrolabe in Sanskrit was written during the reign of Fīroz Tughlaq by Mahendra Sūrī, called *Yantrarāja.*[70]

(iv) *The period of disintegration.* Some of the Provincial dynasties that sprang up after the break-up of Delhi Sultanate also showed interest in the patronage of astronomy. Chief among them was the Bahmanī dynasty of Deccan where Sulṭān Fīroz Shāh Bahmanī ordered the first astronomical observatory in India to be built at Bālāghāt in 810 A.H., some ten years earlier than that of Ulugh Beg's at Samarqand.[71] He was so much interested in these sciences that he himself used to give lectures on *Tadhkira* (a standard work on astronomy by Naṣīruddīn Ṭūsī) thrice a week.[72]

Astronomy under the early Mughals

(i) *Bābur and Humāyūn.* The Mughals brought with them the scientific traditions of Central Asia. Though Bābur relied more on his sword than on astrological prophecies, he, however, did not deviate from his family traditions and employed an astrologer (who must be skilled in astronomy as well) at his court.[73]

But Bābur's son and successor, Humāyūn was himself a great astronomer and spent his time in the company of scholars well-versed in this science.[75] He intended to build an observatory, for which suitable site was chosen and necessary instruments had been collected.[76] But death would not allow this project to be completed. Even before his fatal fall from the stair-case of Sher Mandal, he was engaged in astronomical activities. He was waiting for the rising of the planet Venus.[77]

(ii) *Akbar and Jahāngīr.* Akbar in his zeal for the propagation of his newly invented "Dīn-i Ilāhī" enjoined upon his followers the study of Nujūm (astronomy).[78] It was during his reign that the versatile Amīr Fatḥullāh of Shīrāz reformed the calendar[79] and instituted the new Ilāhī Era. Under his orders Amīr Fatḥullāh, with the help of Abul Faḍl and some Sanskrit scholars translated Ulugh Beg's tables into Sanskrit.[80] Abul Faḍl himself was greatly interested in astronomy and devoted a considerable part of his *Āin-i Akbari* to the rudiments of this science.[81]

Jahāngīr, though not much interested in astronomy was nevertheless very much impressed by the prophecies made by his Court-astrologer Jyotika Rai.[82] Jahāngīr's vazir Āṣif Khān was a great scholar of astronomy.[83]

(iii) *Shāhjahān and Aurangzeb.* Mullā Maḥmūd Jaunpurī, the auther of *Shams-i Bazighah* submitted to the Emperor Shāhjahān his scheme for the construction of an observatory. But it could not be sanctioned due to paucity of funds.[84] Other eminent

scholars of astronomy during Shāhjahān's reign were Mullā Farīd (see below) and Mullā Murshid of Shīrāz.[85]

Aurangzeb's indifference to this science could not arrest the progress of astronomy, which continued, independent of court patronage in the family of Aḥmad Ma'mār specially his son Luṭfullāh, who translated into Persian aṣ-Sūfī's *Ṣuwar-ul-Kawākib*[86] and grandson Imāmuddīn, the author of At-taṣrīḥ, a commentary on Bahāuddīn 'Āmilī's astronomical text *Taṣhrīḥ-ul-Aflāk*.[87] Another scholar of astronomy during this time was Mullā'Iṣmat-ullāh of Sahāranpūr, who translated the commentary of the *Almagest* and *Tashrīh ul-Aflāk*.[88]

Astronomy under the later Mughals

The fratricidal wars that ensued after Aurangzeb's death disrupted the peace of the country, so essential normally for the progress of science. But it is curious to note that as far as astronomy was concerned it was the most fertile period. It was during this period that the first (and also the last, of its kind) observatory was built in India. This was the famous observatory at Delhi (1724) built by Rājā Jai Singh, who also built four other observatories at Jaipūr, Vārānasī, Mathurā and Ujjain.[89] The findings of Delhi observatory furnished the requisite material for the compilation of *Zīj-i Muḥammad Shāhi* (see below).

With the British conquest of the sub-continent, Mughal rule came to an end. Still Graeco-Arabic astronomy struggled hard to survive. And it was during the troubled thirties of the last century that a scholar Ghulām Ḥusain of Jaunpur wrote a great mathematical and astronomical compendium.[90] Besides writing other astronomical works, he also prepared a *zīj* (see below).

In the present century Maulānā Aḥmad Raḍā Khān of Bareilly wrote glossaries on Naṣīruddīn Ṭūsī's *Zīj-i Īlkhānī* and *Jāmi'Bahādur Khānī*[91]

ZĪJES PREPARED IN PRE-MUGHAL INDIA

Zīj-i Nāṣirī

It was the first *zīj* prepared in India, of which history has preserved some details. It was prepared by Maḥmūd bin 'Umar, who dedicated it to the reigning Sulṭān of Delhi Naṣīr al-Dīn Abū-l-Muzaffar Maḥmūd bin Shams al-dīn Iltutmish. Hence its name *Zīj-i Nāṣirī*.[92] As this Sulṭān reigned from 644 to 664 A.H. (A.D. 1246-1265), it must have been completed much before 1265 when observations were being made in the Marāgha Observatory, which were to be utilized as the basis for compiling the renowned "*Īlkhānī Tables*" of Khwāja Naṣīr al-dīn Ṭūsī. The later tables were completed during the reign of Abā Qa'an (1270-1280) who succeeded his father Hulākū Khān. Hence India preceded Iran in the preparation of *zīj* at-least by a decade.

Unfortunately like so many other works of scholarship, this *zīj* also could not withstand the ravages of time. But it was extant in the days of Abul Faḍl who mentions its name in his list of *zījes*[93] (see Appendix A, *zīj* no. 72).

However, Storey, in his work *Persian Literature,* points to a unique manuscript copy of this *zīj* in a private library of Ṭabrīz owned by Ḥusain Aba Nakhjawanī,[94] A transcript of some part of this *zīj* was made and is reported to be in Mullā Firoz Library, Bombay.

Zīj-i Jāmiʿ Maḥmūd Shāh Khiljī

This is the only *zīj* prepared in pre-Mughal India that is accessible to us. A copy of this *zīj* (very probably the unique one) is preserved in Bodlian Library Oxford (No. 1522) of the Persian manuscripts.[95] But unfortunately it is defective, surely at the beginning, as it abruptly begins with "the importance of astronomical science" without the usual praise of the Creator and His Prophet. The second chapter is also wanting, as the last (the twenty-second) section of the first chapter is immediately followed by the colophon, which means in unequivocal terms as follows: "Here ends the book, *Zīj-i Jāmiʿ Maḥmūd Shāh Khiljī*".[96] But the author states at the end of the Introduction (Col. 3.1) that this book consists of an introduction, two chapters and a *khātima.*[97] He also promises in the last section of the book, to describe additional items later on, but this promise has not been fulfilled in the manuscript before us.

The author's name is not mentioned anywhere in the extant folios of the present copy. It might have been stated in the missing folio. Likewise the title of the book is not definitely known. The space (on fol. 3a line 5 of the xerox copy)[98] where the author intended to mention it is blank. The title given above is based on the colophon.

The author commenced this work in 852 A.H. (A.D. 1448) at the request of some of the nobles who were interested in astronomy for preparing almanac. But owing to his preoccupations with other engagements he could not complete it. In 865 A.H. (A.D. 1460-61) he was pressed by his patron, Ḥabībuddīn Muhīb-ullāh to complete it, and accordingly he rewrote it, revised some solved examples and updated the tables. Unfortunately all these drafts were destroyed when Bidar, his native city was devastated and all his belongings were plundered. In the following year 866 A.H. (1461-1462 A.D.) the king conquered the cities of the Deccan and he was commanded by him to prepare an astronomical table, which embodied the gist of previous tables and comprised different astronomical processes. He completed this arduous task and dedicated the book so written to the king.[99] His (the king's) name is also not clearly mentioned.

The book (as the author himself states) was to consist of a *muqaddama* (prolegomena), two chapters, and a *khātima* (epilogue).[100] The *muqaddama* consists of thirty-six sections. Section I is on the definitions of *raṣad* (observatory), *zīj* (astronomical tables) and a number of geometrical terms. Then he gives a short account of arithmetic

which comprises fifteen sections (from section II to XVI). Section XVII is on mensuration. Sections XVIII to XXIV are devoted to astronomical arithmetic based on sexagesimal system. The next twelve sections are on astrolabe; section XXV on the components of the astrolabe and the remaining eleven on the uses of this instrument.

The first chapter deals with the knowledge of different calendars (eras), the determination of planetary motions (with reference to their longitudes and latitudes) and related topics. It consists of twenty-two sections: The first section explains what is meant by a calendar and its several parts such as night, month and year. The next four sections are on the following calendars: Ḥijrī, Roman, Persian and Malikī (instituted during the reign of Saljūq Sulṭān Malik Shāh). The fifth section is on the conversion of these four calendars into one another. Then follows section seven comprising a lengthy description of Turkish (Uighur) calendar consisting of eleven *qism* or parts. Section ten is on the motion of the Sun. Section eleven is on the motion of the Moon. Section twelve is on the motion of the five wandering planets. Section thirteen deals with the description of the above motions, and section fourteen with conjunction and apposition, while the next three sections are devoted to other aspects of planetary motions. Sections eighteen and nineteen deal with astrological problems. Sections twenty and twenty-one are on lunar eclipse and solar eclipse respectively.

In the last (twenty-second) section, the author says that the above-mentioned topics are generally considered sufficient for preparing an almanac. Still there are some more items which are also entered in it such as Coptic, Turkish (?) and Jewish calendars. Some astrologers also add astrological and other predictions including the effects of the moon when it enters different signs of the Zodiac and the twenty-eight lunar mansions.

In the end, the author cautions that astrological predictions are probable and not certain. Only those procedures are worthy to be believed that are based on arithmetical computations, as they are free from doubts except when some error creeps into them.

As to the sources of the *zīj* under review, the author was much impressed by *Īlkhānic Tables* of Khwāja Naṣīr-ud-dīn Ṭūsī.[101] But he differs from him in chapterization. Tusi's *zīj* is divided into four *maqālas,* but the author of *Zīj-i Jāmi'* has redistributed their content. He has also added a number of mathematical topics of interest from other sources. In the prologomena, while giving definitions of geometrical terms, he seems to follow Ṭūsī's *Tadhkira* and the sections on astrolable and its uses seem to be based on his (Tūsī's) *Bist Bāb:* twenty chapters on astrolabe. Besides *Īlkhānic Tables* he does not refer to any other source by name. But there are sufficient reasons to conclude that he consulted a number of *zījes* in vogue at that time, as he himself says, he often intended to prepare a *zīj* by making selections from current *zījes.*[102] However, certain phrases of his *Zīj-i Jāmi'* are reminiscent of Jamshed Kāshī's *Zīj-i-Khāqānī* which had been composed some thirty-six years earlier.

There are only some tables on calendrical conversion, but no astronomical table of planetary motion in the present copy of the *Zīj*.

ZĪJES PREPARED DURING THE REIGN OF GREAT MUGHALS

Tashīl Zīj-i Ulugh Begi

It was prepared by Humāyūn's trusted friend and companion Mullā Chānd, son of Bahā-ud-dīn. He accompanied him (Humāyūn) when he was obliged to flee from India to seek refuge in the protection of Shāh Tahmasb of Iran. But as his queen Hameeda Begam who was about to give birth to his son Akbar, he was obliged to leave her in the fort of Amarkot. He also left Mullā Chānd with her so that he could correctly report the time of birth of the new born and prepare his horoscope which Abul Faḍl has reproduced in his *Akbar Nāma*.

After Humāyūn's death, Mullā Chānd entered the service of his son and successor Akbar, as his court astronomer. It was during this service (in the early part of it) that he made a simplified version of Ulugh Beg's Tables, as he had been persistently requested by his friends to write a *Tashīl* of the *zīj* (of Ulugh Beg). He acceded to their request and prepared a simplified version (easy to understand). A unique copy of this *zīj* is preserved in Jaipur State Library*, Mullā Chānd made some revision and alteration in the arrangement of the original *Zīj-i Ulugh Beg*. He divided his work like the original into three *maqālas*. The first is on different calendars and eras, the second on the determination of the times of ascendents and what pertain to them, and the third on determining the positions of the stars and allied subjects.

In the scheme of arrangement, he has often differed from the original *Zīj-i Ulugh Beg*. Major portion of the first *maqāla* on chronology in the original *Zīj-i Ulugh Beg* is devoted to Chinese and Uighur calendar, whereas Mullā Chānd in the context of changed political, social and cultural conditions did not give importance to this calendar. But what he failed to realize (and subsequent *zīj* writer, e.g. Mullā Farīd and Jai Singh as also Abul Faḍl were obliged to take note of) was the importance of Samvat Era. This lacuna may be due to the fact that he wrote his *Tashīl* before Hindu community and its culture was recognized as something not to be ignored.

The second *maqāla* on spherical trigonometry and astronomy in the original consists of twenty-two chapters, whereas in the *Tashīl* it contains twenty-four chapters. He substituted chapter 15 of the original, "On the Determination of Meridian Line," with a chapter (18th in the *Tashīl*), "On the determination of the inclination of a line that is drawn in the plane of the horizon". He added a new chapter (18th in the *Tashīl*) "On the determination of the sine of the mean motion" between the seventh and eighth chapters of the original. He also added two more chapters between the twenty-first and twenty-second of the original and gave them the title, "On the determination of ascendent from the direction of the star". He also changed the order of chapter seventeen of the original, "On the determination of the

*The author is thankful to the present Mahārājā of Jaipur who permitted him to consult it and take notes.

amplitude of visibility", and assigned it the twelfth place in his scheme. There is not much difference between the original and the *Tashil* in this *maqāla*. Every *maqāla* is followed by a number of tables which he updated from the original with the help of planetary equations.

Zīj-i Shāhjahānī

More important than *Tashil* of Mullā Chānd is the Shāhjahānī tables written by a scholar astronomer.

The author. The author's name was Farīd Uddīn. He came from a family of scholars who were held in high esteem by kings and rulers of bygone days. His father Hāfiẓ Ibrāhīm was a great scholar of his time.[103] Mullā Farīd received his early education from his father. Then he went to the school of Shāh Niẓām of Narnol and learnt from him. Finally he became the pupil of Amīr Fatḥ ullāh Shīrāzī who was decidedly the greatest scholar of intellectual sciences of his time. Under his guidance he acquired a high degree of proficiency in different sciences and was soon recognized as one of the greatest scholars of his time.[104]

He entered the service of Khān-i Khānān, the governor of Gujarāt in 1006 A.H. It was in this year that he wrote an astronomical text named *Sirāj al-istikhrāj* comprising a *muqaddama* (introduction) and nine chapters. He dedicated it to Khān-i Khānān. He continued in his service till 1024 A.H. and perhaps after that as well till he was introduced to Shāhjahān in the second year of his accession, when he presented his newly prepared tables entitled *Zīj-i Shāhjahānī.*[105]

He died, according to the author of *Ṭabaqāt-i Shāhjahānī*, in 1039 A.H. But this seems incorrect as the positions of stars are calculated for the year 1041 A.H. in which year he must have been alive hail and hearty, actively engaged in astronomical activities.[106]

Mullā Farīd wrote many works chief among which were *Sirāj al-istikhrāj*, as stated dedicated to Khān-i Khānān in 1006 A.H. and *Zīj-i Shāhjahānī* to be described shortly. He is reported by the author of *Ma'āthir-i Raḥīmī* to have also written a *zīj* in the name of Khān-i Khānān. This *zīj* is possibly identical with *Sirāj al-istikhrāj* which is not mentioned in *Ma'āthir*.

The genesis of the Tables. The idea of writing a fresh *zīj* was not of Mullā Farīd. It came from Vazir Āṣif Khān who in order to immortalize the name of his son-in-law (Shāhjahān) thought of starting a new era like that of *Jalālī* era of Malik Shāh Saljūqī or Ilāhī era of Akbar. The proposal was put up before Shāhjahān for his approval and consequently a royal decree was issued. Mullā Farīd was commissioned to prepare a new set of astronomical tables with the collaboration of his brother Mullā Ṭayyib and other scholars of Muslim and Hindu astronomy under the over-all supervision of the Vazir Āṣif Khān.[107] As there was not sufficient time for fresh observations and also the age and health of Mullā Farīd did not permit him to endure the strain of astronomical observations (for, if we believe the statement of *Ṭabaqāt i Shāhjahānī*

he could not survive the compilation of his *zīj*) the proposed *zīj* was to be based on *Zīj-i Ulugh Beg* which was the nearest in point of time, most reliable and most correct of all the *zījes*.[108] The result was the *Zīj-i Shāhjahānī*, its full title being *Kārnāma-i Saḥib Qirān-i Thānī, Zīj-i Shāhjahānī.*

The Court Chronicler Muḥammad Sāleḥ Kamboh speaks very highly of this *zīj* which in his words pushed into oblivion and disuse even *Zīj-i Ulugh Beg* on which it was based. The Emperor Shāhjahān was so much impressed by its utility that he ordered it to be translated into *Hindī* (i.e. Sanskrit) for the use of general public.[109]

The Zīj. Like its predecessors, *Zīj-i Īlkhānī* and *Zīj-i Ulugh Beg,* this *zīj* is also divided into four *maqālas,* preceded by a very informative introduction. The latter is sub-divided into five *qisms* or parts dovoted to (1) the nature of a *raṣad* (observatory), *zīj* (astronomical tables), *tashīl* (simplified tables or *zīj* made easy) and *Taqwīm* (almanac), and their uses (first *qism*), (2) special features of this *zīj* (*Zīj-i Shāhjahānī*) on account of which it is to be preferred to other *zījes* of the past (second *qism*), (3) numerical "affinities" between the content of this *zīj* and the royal names and titles (third *qism*), (4) the corrections, inventions (improvements upon) and additions made to Ulugh Beg's Tables (fourth *qism*), and (5) defining the era, year, month, day and its parts (fifth *qism*).

The four *maqālas* are the same as those given in *Zīj-i Īlkhānī* and *Zīj-i Ulugh Beg:* The first *maqāla* on eras consists of ten chapters, e.g. (1) the Ilāhī calendar, (2) Ḥijrī calendar, (3) Greek calendar, (4) Persian (*Yazdjardi*) calendar, (5) Malikī (Jalālī) calendar, (6) transformation of the above five calendars into one another. (7) Indian (Samvat or Śaka) calendar, (8) Transformation of Hijrī calendar into Indian and vice versa. (9) Chinese and Uighur calendar; this is by far the most lengthy chapter, as it consists of ten sections treating different topics relative to Chinese calendar, (10) important days (festivals) of different calendars.

The second *maqāla* entitled "Determination of Times and the Ascendent of every Planet" is concerned with spherical astronomy. The third *maqāla* deals with the determination of the motion of planets and their positions in longitudes and latitudes.

The text of these two *maqālas* is the ad verbatim reproduction of the corresponding *maqālas* of *Zīj-i Ulugh Beg* with occasional changes. But the text of each of these *maqālas* is followed by a great number of tables. For instance in the British Museum Ms copy the text of the second *maqāla* occupies only eight folios, whereas the tables cover some sixty-eight folios. Similarly the text and tables of the third *maqāla* occupy eight and three hundred and nineteen folios respectively.[110]

However the tables were not only copious and updated, but very much improved in comparison with Ulugh Beg's *zīj*. Some of these improvements were borrowed from preceding scholars especially from Mawlānā Rozbahan of Shīrāz and some were his (author) original contribution.[111]

With these additions, Mullā Farīd presented a highly improved edition of *Zij-i Ulugh Beg*, and perhaps the court chronicler Moḥammad Sâleh Kanboh did not exaggerate when he observed that this *zīj* (*Zīj-i Shāhjahānī*) relagated Ulugh Beg's tables into disuse.

ZĪJES PREPARED DURING THE TIME OF LATER MUGHALS

Zīj-i Muḥammad Shāhī

By far the most valuable contribution Medieval India made to the advancement of astronomy was the building of Muḥammad Shāhī Observatory at Delhi (popularly known as Jantar Mantar) and the compilation of *Zīj-i Muḥammad Shāhī* on the basis of its observations.

The Observatory. Muḥammad Shāhī observatory at Delhi is the first of its kind (and also the last) ever built in this country. No other monument of this type had ever been built in India. There were astronomers during the reign of 'Alā'ud-dīn Khiljī capable of erecting an observatory, but they never thought of it. Humāyūn thought of building an observatory, for which suitable site was selected and necessary instruments and requisite equipment had been collected but death did not allow him to bring this idea into practice. Sulṭān Fīroz Shāh Bahmanī of Deccan ordered his court astronomers in 810 A.H. to build an observatory at Bālā Ghāt. They began to build it, but the project had to be left incomplete owing to the death of the chief director.

Providence had reserved the credit of building the first ever observatory in India to the reign of Mughal Emperor Muḥammad Shāh and the untiring efforts of the Rajput Prince Rājā Jai Singh Sawāi.

The Background. The de facto builder of this observatory Rājā Jai Singh was a great scholar of his time in mathematical sciences,[112] (especially astronomy), for which he had a natural aptitude. At the same time he was an orthodox Hindu and insisted on the performance of religious duties and rites at their proper times.[113] To achieve this purpose he took advantage of his astronomical knowledge. He studied astronomical tables, not only those based on Hindu astronomy (*siddhānta jyotiṣa*), but also on Muslim *'Ilm ul-Hay'at* (Graeco-Arabic astronomy) and modern European astronomy. But the times of different celestial phenomena (especially of eclipses) which he calculated with the help of these tables would not very often tally with those of their actual occurrence.[44] He brought this matter to the knowledge of the Emperor who commanded him to build, with the collaboration of the exponents of different systems of astronomy (Hindu *Jyotiṣa*, Muslim *'Ilm-ul-Hay'at* and European astronomy), an observatory and prepare a fresh set of astronomical tables based on its observations.[115]

The Building of the Observatory

He obeyed the imperial command and set to work. But the difficulty was that there existed no model of an observatory.[116] To surmount this obstacle he studied

works of Muslim scholars on the construction and uses of astronomical instruments and got a number of them, like those used by the astronomers of Ulugh Beg's observatory at Samarqand, manufactured by local artisans.[117]

But these metallic instruments could not satisfy him, as besides being small, not admitting fine and minute divisions, they soon became unserviceable. Hence he was obliged to replace them by masonary instruments made of lime and stone[118] (actually huge buildings). In the preface of *Zīj-i-Muḥammad Shāhī* he gives the names of three of them, *Samrāṭ Jantar, Jai Prakāsh* and *Rām Jantar*. With their help, observations were made and recorded in a fresh *zīj* which was dedicated to the Emperor Muḥammad Shāhī. Hence it was called *Zīj-i-Muḥammad Shāhī*. It was completed in 1728 A.D.

The Zīj. Like the astronomical parts of the preceding *zījes (Zīj-i Īlkhānī, Zīj-i Ulugh Beg* and *Zīj-i Shāhjahānī) Zīj-i Muḥammad Shāhī* is also divided into three *maqālas*.

The first *maqāla* is on calendars. The Raja was more practical and therefore would not waste his time in describing obsolete eras, such as Greek or Persian eras. He was content with (i) the Hijrī era which was in vogue at that time (ii) the Muḥammad Shāhī era, which he instituted in order to immortalize the name of his overlord, (iii) the Hindu Era or Samvat which was current among the majority community and hence a social necessity, and (iv) the Christian era for which he foresaw the importance to be attached in future.

Consequently the first *maqāla* is divided into following four chapters:

I On the determination of Hijrī Era

II On Muḥammad Shāhī Era

III On Christian Era, and

IV On Indian Era, known as Samvat. This chapter is further sub-divided into two sections, e.g. (a) finding the Samvat from Hijrī year, and (b) finding Hijrī year from the Samvat.

On the other hand, the second *maqāla* is divided into nineteen chapters as follows:

I On sine and versine.

II On the determination of the tangent of a quantity and vice versa.

III On the determination of the second declination of the ecliptic from the celestial equator.

IV On the determination of the distance of a star from the celestial equator.

V On the determination of the maximum upper and lower culmination of a star in equatorial zone.

VI On the determination of the ascendent of (places on) terrestrial equator.

VII On the determination of the equation of day, the diurnal arc, the nocturnal arc and the hours of day and night.

VIII On the determination of ascendents (finding ascension as a function of latitude).

IX On the converse of the determination of ascendents.

X On the determination of the ascendent of transit.

XI On the determination of the ascendent of the rising and setting of stars for terrestrial equator.

XII On the determination of the azimuth from the upper and lower culmination.

XIII On the determination of the upper culmination from the azimuth.

XIV On finding the terresterial meridian (or line of north and south).

XV On finding the longitude and latitude (of a place).

XVI On the determination of the amplitude of the time of visibility.

XVII On the determination of the distance between two stars.

XVIII On the determination of the ascendent from the upper culmination.

XIX On the determination of the upper or lower culmination of the stars from ascendents.

This *maqāla* ends with a conclusion on the importance of a gazetteer for the preparation of an almanac, and therefore, on the description of the longitude and latitude of some important cities. As a whole, the second *maqāla* is an ad verbatim reproduction of the latter with minor changes. The most prominent of these changes was the deletion of the chapter on the determination of the direction of *Qibla*. (Mecca), a topic that had been invariably treated in all astronomical texts and tables from the time astronomy was studied by Muslims.

The third *maqāla* entitled "The determination of motions of stars and their positions (longitudes and latitudes)" is on planetary motions only. For other topics discussed in the corresponding *maqālas* of Īlkhānīc tables and those of Ulugh Beg, he added a *khātima*, the end-chapter.

However, the third *maqāla* of *Zij-i-Muḥammad Shāhi* consists of a *muqaddama* and four chapters. The *muqaddama* is on the equation of time. The four chapters are devoted to the motions of the Sun, the Moon, the outer planets (Saturn, Jupiter and Mars) and the inner ones (Venus and Mercury). Each of the first two chapters is further sub-divided into three sections, the first on mean motion, the second on their *ṭaqwīm* and the third consists of different tables, such as that of mean motion, equation etc. The last two are divided into two sections each, the first on mean motion and the second on determining the *taqwīm*.

The *khātima* consists of seven sections as follows :

I. Lunar eclipse.

II. Solar eclipse.

III. Determination of the time of the visibility of the new Moon. (It is in this section that the author claims to have got a telescope constructed by artisans of his household and then verified with its help some of the discoveries made by Galileo, see below).[119]

IV. Appearance and disappearance of wandering planets.

V. Appearance and disappearance of the so-called fixed stars.

VI. Rising and setting of lunar mansions.

VII. The positions (celestial longitudes and latitudes of some sixty and odd stars determined by the astronomers of Muḥammad Shāhī Observatory).

The Tables. There are about 147 tables in this *zīj* (according to Aligarh MS) Their *maqāla*-wise distribution is as follows: first *maqāla*-10; second *maqāla*-64 (including two trigonometrical tables, one of sines and the other of tangents, and a geographical gazetteer giving longitudes and latitudes of some 136 places); third *maqāla*-67; *khātima*-6. In the third *maqāla* on planetary motions, the number of tables appended with every planet is as follows: Sun-6; Moon-21; Mars-7; Jupiter-8; Saturn-8; Venus-7. These figures differ from those given by Hunter in his article "Some account of the Astronomical Labours of Jaya Sinha", published in *Asiatick Researches*, 1793. According to him these figures are as follows: Sun-9; Moon-12; Mars-11; Jupiter-10; Saturn-11; Mercury-11; Venus-11. It seems the manuscript consulted by Hunter was different from the Aligarh one, which is substantially in agreement with a number of other mss copies. For instance according to Aligarh MS, the number of early *zījes* studied by Jai Singh as recorded by him in the preface of *Zīj-i Muḥammad Shāhī* is four whereas Hunter gives only three, omitting *Zīj-i Shāhjahānī* mentioned in other copies.

Special Features of Zīj-i Muḥammad Shāhī. This is the first *zīj* prepared in the East that clearly shows the influence of modern European astronomy, both in theory as well as in practice.

(a) The stories of new discoveries made in Europe were constantly trickling into the learned circles of India (specially of Delhi) through European scholars who under the title of *Dānāyān-i Firang* (wise men of the West) constituted an important section of the intelligentsia. It was through them that the astronomers of the Raja came to know how after a long series of trials and errors, Kepler succeeded in explaining the motions of different planets. So these scholars after a bitter controversy agreed to employ Kepler's first law for solving the anomalies of planetary motions, only if it was not in conflict with their basic principle of geo-centric universe. For this purpose they made two modifications in this law.

(i) They divested it of its helio-centric context, and

(ii) They excluded from its purview the Earth, which still continued to occupy in their system the middle, if not the central, position. Thus they extended it to regulate even the motion of the Sun, which in Kepler's theory was stationary and occupied a focal, if not the central, position.

(b) It was the first observatory in India that employed telescope for astronomical observations. The astronomical mission sent by Jai Singh to Portugal brought with them a telescope made there.[120] Then he got another telescope manufactured by local artisans, as he states in the *zīj* itself.

"As our artisans have constructed the telescope so excellent that with its aid we can see bright and luminous stars even about midday in the middle of the sky. By employing such powerful telescope, the newmoon can be seen ever before the time, the astronomers have determined for its rays to begin emanating. And also after it has entered the prescribed limit of its invisibility, it still remains visible (through the telescope).[121]

Then he set to verify what was told to him about the discoveries made by Galileo and others, and to his great joy he found them true. He himself states the results of new experimentation.

"We also found the form and behaviour of some of these planets contrary to what the earlier scholars have recorded in current works. They are as follows:

First : We observed with our own eyes that Venus and Mercury obtain light, like the Moon, from the Sun, because we found that their light is diminished or increased according to their distance from the Sun.

Second : We have observed Saturn and found that it has the shape of an ellipse, i.e. out of its two diameters intersecting at right angles, one is smaller than the other.

Third : We found four shining stars approximately near the equator of Jupiter revolving round it.

Fourth : We saw a number of spots distinct from one another on the surface of the solar disc and found them completing their round on the solar disc, along with the rotation of the Sun itself, in about one year."[122]

One more deviation was made by Jai Singh from the traditional Graeco-Arabic astronomy which conceived the so-called "fixed stars" as stationary. But he proposed an altogether different theory and observed in *Zīj-i Muḥammad Shāhī.*

"Those stars that are termed "Fixed Stars" in the terminology of astronomers are not fixed and stationary in reality. Nor do they move with one rate of velocity, but with different velocities.[123]

(c) The Rājā and his colleagues also solved a baffling problem of trigonometry. This related to finding out the sine of one degree and its parts (minutes and seconds etc.). Ulugh Beg by devising a scientific method for finding the sine of an angle one third of another of known sine, was able to compute geometrically the sine of one degree. But Jai Singh and his colleagues went one step further and found out geometrical method for determining the sine of one minute etc. as well. He says :

"As the determination of the sine of one minute is dependent on the method of finding the sine of an angle, one fifth of another of which the sine is known, we with the grace of the Creator of the Universe were enabled to determine the sine of an angle, one fifth of another of known sine so that we could determine geometrically the sine of one minute as well."[124]

Jāmiʿ Bahādur Khānī

It is a great compendium of mathematical and astronomical sciences. The author Maulānā Ghulām Ḥusain of Jaunpur came of a learned family. He received his early education from his father. Then he went abroad for higher education and acquired proficiency in different mathematical sciences, which included the science of astronomy. He was invited by Raja Bahādur Khān of Tikari, where he composed *Jāmiʿ Bahādur Khānī* (1835) and *Zīj-i Bahādur Khānī* (1844) and dedicated them to the Raja, hence their titles. Afterwards he went first to Banaras and finally to Murshidabad where he died in 1279 A.H.[125]

He began to write this compendium *(Jāmiʿ Bahādur Khānī)* in 1833 and completed it the next year. Within a space of one year and two months he wrote such a voluminous treatise comprising 657 pages of big size.[126] As an apology for writing this book, he says, "Since the time of al-Barjandī (died 1249 A.H.), no comprehensive book dealing with astronomy and allied sciences (arithmetic, geometry and optics) and at the same time matching with *Almagest* and commentaries on "*Tadhkirah* (of Naṣīr al-Dīn Ṭūsī) has appeared in Persian language......so I undertook to write this book."[127]

The *Jāmiʿ* comprehensively deals with the following branches of mathematics: geometry, optics, arithmetic, trigonometry, astronomy, and preparation of *zījes* The chapter on "Astronomy" comprises 256 pages. The section on introduction deals with the definition of astronomy and its fundamental principles, e.g. form of celestial sphere and terresterial elements, astronomical instruments and the techniques of observation, form of component spheres and details of their composition and velocities, description of the Earth and peculiarities of different zones and distances and sizes of different celestial bodies.

In the epilogue, the author discusses the reasons of difference between the findings of various observatories.

No other book on astronomy on the pattern of *Jāmiʿ-Bahādur Khānī* is known except al-Bīrūnī's "*Kitāb at-Tafhīm*", of which the first two parts are devoted to geometry and arithmetic and the remaining three to astronomy, astrolabe and astrology. But the treatment of astronomy is not so thorough as in[128] *Jāmiʿ Bahādur Khānī*".

There are a number of astronomical tables, besides trigonometrical tables, geographical gazetteer and a revised star catalogue. The importance of the tables consists in the fact that their proof correction was meticulously done by the author

himself with the result that it is free of errors, specially in figures, which is so common in astronomical works whether printed or hand-written.

Ẓij-i Bahādur Khāni

It is perhaps the next best *zij* after *Ẓij-i Muḥammad Shāhi*, as it was completed with the help of fresh astronomical observations made by the author. As regards his proficiency in astronomy, no further proof is needed after a thorough study of his *Jāmi' Bahādur Khāni* and other astronomical works such as his commentories on Ptolemy's *Almagest* and Bahāuddīn Āmuli's tract on astrolabe etc.

The Background. After the author Ghūlam Ḥusain completed *Jāmi' Bahādur Khāni* in 1834 and dedicated it to his patron Rājā Khān Bahādur Khān, he submitted to him the following proposal:

> "Now that I have made a comprehensive compendium of mathematical sciences, it is hoped that your honour would give your attention to what is the practical result of all these sciences, and that result is the compilation of a fresh set of astronomical tables, which is in need of constant revision and reform in all successive periods of time, and this must be based on fresh astronomical observations.
>
> But the later project has never been possible without the (financial) assistance from the upper (wealthy) class of the society. Moreover, recently European scholars have designed and manufactured highly sophisticated and fine astronomical instruments, which have made astronomical observations independent of big and clumsy instruments used by Graeco-Arabic astronomy. It may also be submitted that many of these new instruments are already there in the stores of your household.
>
> "Hence if (fresh) observations of stars (and their different aspects) are made for some years, the difference between the observed times (of their actual occurrences) and that which is computed with the help of *Ẓij-i Muḥammad Shāhi* will be eliminated. Moreover, this humble self has been observing and keeping a proper record of these observations and this will also help in the preparation of the new Tables."[129]
>
> In response to this request of the author, his patron observed :
> "We ourselves had such idea in our mind from a long time, and now that you have submitted this proposal, we seriously intend that this project be duly executed."[130]

This remark of the Rājā encouraged the author, who single-mindedly devoted himself to the observations of different aspects of the stars (planets) such as their longitudes, latitudes and their diameters and also to systematically record their periods of changes. He occupied himself in this activity for six years besides the earlier nine years, as stated above. He also added to the knowledge so gained during

these fifteen years, the findings of earlier astronomers and with the resultant knowledge corrected and revised different astronomical tables, such as those of the inclinations, mean motions and equation of different planets and entered them in a fresh *zīj*, named "*Zīj-i Bahādur Khānī*" so that any one who so desires, might determine with its help, the almanacs of fixed stars and planets, occurrences of eclipses, time of visibility of newmoon, the relative positions and conjunctions of different planets for a long time to come.

The Zīj : It consists of a *muqaddamah* and seven chapters. The *muqaddamah* is on the nature of a *zīj* and discusses the reasons for the necessary revision of the tables in successive periods of time. The various *maqālas* deal with the following topics: (1) arithmetical computation both using Indian numerals of decimal system of notation and the sexagecimal system; (2) on different eras and their reductions from one to the other; (3) determination of the time of ascendent and allied matter; (4) determination of the motions of stars, their longitudes and latitudes, determination of solar and lunar eclipses, visibility of new moon, appearance and disappearance of remaining five wandering planets and fixed stars etc.; (5) determination of *tithi, nakṣatras joga, karaṇa* and the method of finding them; (6) the relative positions of the planets with respect to one another and their conjunction and some arithmetical computations relating to astrology; and (7) astrology and its predictions relating to the ascendents of the year and personal horoscopes, and determinations of auspicious times.

In the second *maqāla,* besides discussing the usual eras, i.e. Creation, Deluge, Coptic (i.e. pertaining to Ba<u>kh</u>t Naṣar), Greek (after Alexander, the Great), Chinese and Uighu, Hijrī, he has also discussed the Samvat and Gregorian calendars.

The third *maqāla* consists of some twenty-three chapters more or less the same as as in Uighur Beg's tables and *Zīj-i Muḥammad Shāhī.*

The Tables. These tables concern as usual the trigonometrical tables of sine, tangent, and cotangent; first inclination; second inclination; *Maṭāliʿ al-Burūj;* hours of midday, and the number of *gharhies* for the total day and night at the place of observation; the real hours corresponding to the degrees of Sun's motion, and geographical gazetteers. Then there are a number of tables corresponding to that in the 2nd *maqāla* of the *Zīj-i Muḥammad Shāhī.* The tables pertaining to the *taqwīm* of the Sun were prepared one for his native city of Jaunpūr and the other for Calcutta. The tables pertaining to the mean equations, distances and (apparent) diameters of the Sun were computed from his own observations, as he claims.

Special Features of Zīj-i Bahādur Khānī

Besides the corrections made by the author in the earlier tables of mean motions etc. of the *zījes* of ancient astronomers, this *zīj* has a number of special features. It has a *maqāla* on the mathematics of astronomy. The terms and symbols used in almanac are explained. Three additional calendars Bangla, Gregorian and Fasli are added to the current eras. Tables of *tithis, nakṣatras, karaṇas* etc. according to Indian *Jyotiṣa* are also incorporated to help those who act according to *Jyotiṣa.* Compound

equations of lunar anomalies are tabulated corresponding to degrees of zodiacs. The ancients computed *Maṭāliʿ al-Burūj* to the latitude of the extremity of habitable world and ignored those that were beyond that latitude. But as the Europeans have explored the land beyond that limit, consequently the tables of *Maṭāliʿ ul-Burūj* to latitude 67 degree which is the complement of solar eclipticity (i.e. 23½ degree) are also added to the existing ones. As necessity often arises for astrological predictions, a chapter on astrological prognostications is also added.[131]

Minor Zijes Prepared in India

Some more minor *zijes* are also reported in catalogues of Indian libraries to have been prepared in this country. But as their microfilms were not available, details about them cannot be given. They are :

Zij-i Ashki by Kundan Lāl Ashkī,[132] Central Library, Hyderabad;
Zij-i Hindi by Mīrzā Gul Beg Munajjim,[133] Raḍā Library, Rampur;
Zij-i Niẓāmi by Khwāja Bahādur Ḥusain Khān,[134] Central Library, Hyderabad;
Zij-i Mīr ʿAlami by Safdar ʿAlī Khān,[135] Central Library, Hyderabad;
Zij-i Safdari by Safdar ʿAlī Khān,[136] Sālār Jang Library, Hyderabad; and
Zij-i Sulaimān Jāhi by Rustam ʿAlī Khān,[137] Raḍā Library, Rampūr.

But more important is a glossary on *Zij-i Īlkhāni*.[138] It was written by a great scholar of modern times, Maulana Ahmad Raza Khan of Bareilly in 1892-93 A.D. This glossary is based on the commentary of the renowned Persian scholar Niẓāmuddīn Aʿaraj of Nīshāpūr. The learned author wrote only on the second *maqāla* of Īlkhānic Tables, but has provided very useful information, not generally found in other works on astronomical texts and tables.*

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APPENDIX—A

Zījes Enumerated In Ā'īn-i Akbarī

1. *Zīj-i Majūr* (Amajur, the Turk).
2. *Zīj-i Ibburkhas* (Hipparcus).
3. *Zīj-i Baṭlimūs* (Ptolemy).
4. *Zīj-i Fīthāghurath* (Pythagoras).
5. *Zīj-i Zardasht.*
6. *Zīj-i Thāūn Iskandaranī* (Theon of Alexandria).
7. *Zīj-i Sabat-i Yūnānī.*
8. *Zīj-i Thābit bin Qurrah.*
9. *Zīj-i Ḥasan bin Sinān.*
10. *Zīj-i Thābit bin Mūsā.*
11. *Zīj-i Muḥammad bin Jābir Battānī* (Albatignius).
12. *Zīj-i Aḥmad bin 'Abdullāh Jaha* (Ḥabash).
13. *Zīj-i Abū Rayḥān* (very probably *al-Qānūn al-Mas'ūdī*).
14. *Zīj-i Khālid bin 'Abdul-Malik* (one of the participants in al-Mamūn's observatories).
15. *Zīj-i Yaḥyā bin Abī Manṣūr* (very probably the famous *az-Zīj-ul-Mumtaḥan*).
16. *Zīj-i Ḥāmid* (the tables of Abū Hāmid Aḥmad bin Muḥammad as-Saghanī).
17. *Zīj-i Mughnī.*
18. *Zīj-i Sharqī.*
19. *Zīj-i Abul Wafā' al-Buzjānī.*
20. *Zīj-i Jāmi' Kaya Koshiyār.*
21. *Zīj-i Bāligh Kaya Koshiyār.*
22. *Zīj-i 'Aḍūdī Kaya Koshiyār.*
23. *Zīj-i Sulaymān bin Muḥammad.*
24. *Zīj-i Abū Ḥāmid Anṣārī.*
25. *Zīj-as Safā'ih* (of Abū J'afar al-Khāzin).
26. *Zīj-i Abul Farh* (? Taraj) *Shirazi.*
27. *Zīj-i Majmū'a.*
28. *Zīj-i Muktār.*
29. *Zīj-i Abul Ḥasan Ṭūsī.*
30. *Zīj-i Aḥmad bin Isḥāq Sarkhāsī* (probably Aḥmad bin Muḥammad bin aṭ-Ṭayyib as-Sarkhāsī, the pupil of alkindī and the teacher of the Caliph al-Mu'taḍid).
31. *Zīj-i Fazārī* (probably Ibrāhīm bin Ḥabīb al-Fazārī. He based his *zīj* on *Brahmasphuṭa Siddhānta*).
32. *Zīj-i Hārūnī* (probably Hārūn al-Munajjim, an astrologer of Baghdād).
33. *Zīj-i Adwār-i Qarayn* (a table containing cycles of conjunctions).
34. *Zīj-i Y'aqūb bin Ṭāriq* (probably his *Zīj al-Maḥlūl*).
35. *Zīj-i Khwārazmī* (Muḥammad bin Mūsā Khwārazmī).
36. *Zīj-i Yūsufī.*

37. *Zij-i Wafi.*
38. *Zij-i Sam'āni* (according to al-Fihrist Sam'ān was the commentator of Ptolemy's Canon).
39. *Zij-i Jozharayn* (a table ralating to Jouzharayn, which are the head and tail of Draco, or the two points of intersection of the ecliptic and the orbit of the Moon).
40. *Zij-i Ibn Saḥra.*
41. *Zij-i Abul Faḍl Mashāzi* (probably Māshā' Allāh, the Jewish astrologer Ibn al-Athra).
42. *Zij-i Aāsimi.*
43. *Zij-i Kabir Abu Ma'ashar* (Latin Abbumaser first an opponent and afterward a pupil of Al-Kindī and a prolific writer).
44. *Zij-i Sanad bin 'Ali* (a renowned astronomer and participant in al-Mamun's observatory).
45. *Zij-i Ibn-ul-A'alam* (court astronomer and teacher of Buwahid Prince Adudud Daulah. His tables were relied upon by Naṣīruddīn Ṭūsī *in the preparation* of his *Zij-i Īlkhāni*).
46. *Zij-i Shahryarān* (the famous Persian astronomical tables of Sasanid Period, translated by al-Tamimi).
47. *Zij-i Arkand* (Sanskrit *Ahargaṇa*. Al-Bīrūnī revised its earlier Arabic translation).
48. *Zij-i Ibni-ṣ-Sufi.* (The Epitome of Ulugh Beg's Tables by Shaikh Muhammad bin Abil-Falah aṣ-Sufī al-Miṣrī with additional tables and notes).
49. *Zij-i Sahlān Kāshi.*
50. *Zij-i Ahwāzi* (probably the same, who wrote according to *al-Fihrist* a commentary on Euclid's *Elements*).
51. *Zij-i 'Urūs Abū J'afar Bushanji* (not traceable).
52. *Zij-i Abul Fatḥ* (the same who according to Ḥājīkhalīfā ammended the Samarqandī Tables).
53. *Zij-i Akkah Rahbi* (not traceable).
54. *Zij-i Qānūn-i Mas'ūdi* (of al-Bīrūnī).
55. *Zij-i Mu'atabar Sanjari* (of Abul Fatḥ 'Abdur Raḥmān al-Khāzinī, which he dedicated to the Saljūq Sulṭān Sanjar).
56. *Zij-i Wajiz Mu'atabar* (probably an abridgement of no. 55).
57. *Zij-i Aḥmad bin 'Abdul Jalil as-Sijzi* (an eminent astronomer of mid-tenth century A.D. who was the advocate of helio-centric system among the Muslims).
58. *Zij-i Muḥammad Jamasp Ṭabri* (not traceable).
59. *Zij-i 'Adli* (or 'Adanī).
60. *Zij-i Asābi'ai.*
61. *Zij-i Taylsān.*
62. *Zij-i Sulṭān 'Ali Khwārazmi* (full name of the author was 'Alī Shāh bin Muḥammad bin al-Qāsim. He was the author of a table called *Shahi.* He also epitomised Īlkhānic Tables and gave it the name of *'Umdat-ul-Īlkhānia*).
63. *Zij-i Tākhir (?) Naswi.*
64. *Zij-i Kirmāni.*

65. *Zij-i 'Alāi' Shirwāni* (full name of the author was Fakhruddīn Abul Ḥasan 'Alī bin al-Karīm ash-Shīrwānī, also known as al-Fahād. He was the author of another five tables).
66. *Zij-i Rāhiri* (probably Zāhidī, not traceable).
67. *Zij-i Mustaufī.*
68. *Zij-i Muntakhab Yazdī.*
69. *Zij-i Abu Rāzi Yazdī.*
70. *Zij-i Qaydūrah* (not traceable).
71. *Zij-i Iklīlī.*
72. *Zij-i Nāṣirī* (very probably of Muḥammad bin 'Umar Rāzī and dedicated to Nasīruddīn Maḥmūd, son of Iltutmish.
73. *Zij-i Mulakhkhaṣ.*
74. *Zij-i Dastūr.*
75. *Zij-i Murakkab.*
76. *Zij-i Maqlāma.*
77. *Zij-i 'Aṣā.*
78. *Zij-i Shastalah.*
79. *Zij-i Mas'il.*
80. *Zij-i Khatā'i.*
81. *Zij-i Dailamī.*
82. *Zij-i Mufrad Muḥammad Ayyūb* (a very important *zij* in Persian).
83. *Zij-i Kāmil Abū Rashīd* (based on Albatignius' Tables, *Zij-i Al-Battani*).
84. *Zij-i Īlkhāni* (of Naṣīruddīn Ṭūsī).
85. *Zij-i Khāqānī* (of Ghiyāthuddīn Jamshīd Kāshī).
86. *Zij-i Gurgānī* (i.e. Ulugh Beg's Tables. The author, Ulugh Beg was the grandson of Tīmūr Gurgānī. Hence this title. The original title of this *zij* was *Zij-i Jadīd Sulṭānī*).

APPENDIX—B

ZIJES ENUMERATED BY MULLĀ FARĪD IN HIS *Zīj-i Shāhjahānī*

1. *Zīj-i Jamia*ʻ of Koshyār
2. *Zīj-i Balīgh* of Koshyār
3. *Zīj-i Mufrad* of Muḥammad Ayyūb Ṭabrī
4. *Zīj-i Kāmil* of Abū Rashīd Dānishī
5. *Zīj-i Sālār* of Ḥusayn Sālār
6. *Zīj-i Mughni*
7. *Zīj-i Muṣṭaufī*
8. *Zīj-i Muḥkam*
9. *Zīj-i Zāhidī*
10. *Zīj-i Tākhir* of ʻAli Muṣṭaufī Shīrwānī Bakwāhī
11. *Zīj-i Sanjari* of ʻAbdur Raḥmān Khāzinī
12. *Zīj-i Alā'ai* (which he says was based on *Zīj-i Sherwānshāh*)
13. *Zīj-i ʻUmda i Īlkhānī* by ʻAlī Shāh Khwārazmī
14. *Zīj-i Khāqānī* which was the compliment of Īlkhānī Tables by Maulana Jamshed Rāshī.
15. *Zīj-i Sultani* of Muhammad bin Khwaja ʻAlī Wamkahiwī
16. *Zīj-ī Abū Ḥāmid Anṣāri*
17. *Zīj-i Abul Faraḥ Shīrāzī*
18. *Zīj-i Abul Ḥasan Ṭūsi*
19. *Zīj-i Kāfī Iskandari*
20. *Zīj-i Adwar Akwar*
21. *Zīj-i Ashrafī*
22. *Zīj-i Raḥīmī*
23. *Zīj-i Kāsifī*
24. *Zīj-i Shāṭiri* (may be *Zīj-i Ibn-i Shāṭir*)
25. *Zīj-i Mazharī*
26. *Zīj-i Quṭbī*

3 SURVEY OF STUDIES IN EUROPEAN LANGUAGES

S. N. SEN

The beginnings of the study in European languages of ancient Indian astronomy can hardly be fixed with any degree of certainty. Indian astronomy appears to have reached Europe through Arabic astronomical literature during the eleventh-thirteenth century. In this transmission Spain played a crucial part. The starting point was the preparation of the Arabic version, *Az-Zij* as-*Sindhind* (*c.* 770), of one of the Indian *siddhāntas,* possibly the *Brāhmasphuṭasiddhānta* of Brahmagupta. This work, through revisions and refinements by subsequent authors such as al-Fazāri, Ya'qūb ibn Ṭāriq, al-Adamī, al-Khwārizmī, al-Hasan ibn Misbāh, an-Nairīzī, al-Majriṭī, as-Saffār and others, exerted considerable influence first among the Eastern Arabs and subsequently among the Western Arabs of Spain.[1] Maslama al-Majriṭī (fl. 1000) of Cordova edited al-Khwārizmī's astronomical tables which were translated into Latin by Adelard of Bath (*c.* 1142).[2] Lynn Thorndike published and translated an anonymous fifteenth century Latin MS Ashmole 191 II, in which computations were made for the geographical latitude of Newminster, England of the year 1428, using astronomical parameters and tables (trigonometrical sine table for $R=150$) characteristic of Hindu astronomy.[3] Thus, with the revival of learning in Latin Europe, particularly during the active period of translation from Arabic into Latin, certain Hindu astronomical elements and tradition inevitably passed into Western Europe.

SEVENTEENTH CENTURY BEGINNING

Direct study of Indian astronomy on the basis of Sanskrit manuscripts started towards the end of the seventeenth century when M. de la Loubére, French ambassador in Siam brought to Paris in 1687 a portion of a manuscript containing rules for the computation of longitudes of the Sun and the Moon. The manuscript was referred to the celebrated astronomer John Dominique Cassini, then director of the Paris observatory. The interpretation of the manuscript which did not contain any example nor any commentary proved a difficult task and called for, as Bailly put it, all the skill of the great astronomer to extract the correct astronomical elements.[4] In 1691, Cassini communicated the results of his investigations for publication in La Loubére's *Relation de Siam,* which were reprinted eight years later in the *Mémoires* of the French Royal Academy.[5]

The Siamese manuscript opened with rules for the computation of *ahargaṇa* or the number of civil days elapsed from the beginning of an era up to the date on which the mean longitude of the Sun (or the Moon) was desired. From the use of the fraction $\frac{11}{703}$ as the ratio of omitted lunar days to the total number of lunar days for the epoch, Cassini calculated the length of the synodic month as 29d 12h 44m

2.39s (703 lunar months=20,760 days). He further established the equivalence of 228 solar months (19 years) with 235 lunar months, implying that the Metonic cycle was known to the compilers of such astronomical rules. From another calculation of the era of 292207 days during which the Sun underwent 800 revolutions Cassini calculated the sidereal year length as 365d 6h 12m 36s, agreeing with the Pauliśa value of the year. The eclipse calculations suggested to him a place called 'Narsinga' (lat. 17°22'N) in the Godavari district in Orissa. Other findings included the period of revolution of the Moon's apsis as 3232 days, the Sun's equation of the centre (largest) as 2°12′ and the Moon's 4°56′. By comparing these elements with those of the *Pauliśa-siddhānta* in Varāhamihira's *Pañcasiddhāntikā,* as summarized by al-Bīrūnī in his *India,* James Burgess suggested that the Siamese manuscript was based in all probability on the *Pauliśa-siddhānta.*[6]

PROGRESS IN THE EIGHTEENTH CENTURY : LE GENTIL TO HUNTER

Cassini's work marked the recrudescence of an interest in ancient Indian astronomy among astronomers as well as scholarly circles in Europe. Early in the 18th century T. S. Bayer, in an appendix to his history of the imperial Graeco-Bactrians, furnished some information about Hindu astronomy, such as the Sanskrit and Tamilian names of planets, days of the week, months, and the twelve signs of the zodiac.[7] This brief notice assumed some importance as it was accompanied by a note by Leonard Euler on the length of the Hindu year of 365d 6h 12m 30s. About this time Beschi, in his Tamil Grammar, gave an account of calendar making in Tamil countries and also published a Tamil astronomical work under the title *Tiruchabei Kanidam.*

Le Gentil and Bailly

If the notices of Bayer and Beschi went almost unheeded M. Le Gentil's lengthy account of Hindu astronomy in the *Histoire de l'Academie Royal des Science* and in the *Mémoires* stimulated a fresh interest in the subject. Le Gentil's work on Brāhmaṇa astronomy was undertaken in strange circumstances. He was a trained observational astronomer, having received his early training at the hands of Delisle at the Collége Royal and Jacques Cassini, Cassini de Thury and Maraldi at the Paris Observatory. During the international expeditions for observing the transits of Venus in 1761 and 1769 he was deputed to India to observe the transits, important for an accurate determination of the solar parallax, but being unlucky to observe the phenome na he spent a good part of his stay in India in his researches on Brāhmaṇa astronomy.[8] He obtained his information on various astronomical tables and rules from calendar-makers in and around Pondicheri. Some of these tables were taken from the *Laghu-Āryasiddhānta,* a text then extensively used in the Madras Presidency. He dealt in detail with the methods of computing eclipses in accordance with the 'Vakyam process', developed originally for the year A.D. 499 but adapted to A.D. 1413. In these computations, the revolution of the Moon's node was taken to be 6792.36 days and the equation of the Sun's centre 5°1′. Other features of his study included the names of 27 *nakṣatras* and the identification of the principal stars or star

groups associated with each of them, the relationship between planetary names and weekdays in which Śukravāra served as the beginning. Le Gentil's method of studying ancient and medieval astronomy by collecting information from calendar-makers and other practical astronomers who memorized various tables, rules and relied upon mnemonic devices and reconstructing from them correct astronomical elements and procedures was also followed by Warren; and their tables and materials have in the present century lent themselves to useful and interesting analysis.

The threads of investigations of Cassini and Le Gentil were then taken up by another capable French astronomer M. Jean Sylvain Bailly (1736-1793) whose *Traité de l'Astronomie Indienne et Orientale* served as a classic work on Hindu astronomy for many years to come. Bailly had not only the advantage of previous studies by his two distinguished compatriots, but had also the opportunity of consulting two Sanskrit manuscripts which had found their way to Paris. The first was the *Pañcāṅga Śiromaṇi* sent by Father Patouillet from India to astronomer M. Joseph de Lisle in 1750 and the second procured by the Jesuit Father Xavier du Champ in Pondicheri and sent to de Lisle via Father Gaubil in China in 1760. The provenance of the Xavier manuscript was at first supposed to be Krishnapuram, but Bailly suggested it to be Narsapur or Masulipatnam. He also associated the Patouillet MS with Narsapur, but was more inclined to relate it to Benares having the same meridian as Narasimhapur whose location again was questionable.[9]

The Xavier manuscript gave the epoch from March 10, 1491 and yielded constants good for the epoch A.D. 499 (Āryabhaṭa). The equations of the Sun and the Moon agreed with those contained in the *Sūrya-siddhānta*. Bailly calculated the lunar eclipse of July 29, 1730, the longitudes of Jupiter and Mercury for the same date and the solar eclipse of July 1731 on the basis of the tables and rules given in the manuscript and found the agreement to be good. For the Patouillet manuscript he computed the epoch to be A.D. 1569, although some of the elements conformed to A.D. 1656. The text gave the year length as 365d 6h 12m 30s, the greatest equations of centre for the Sun and the Moon as 2°10′34″ and 5°2′26″ respectively and tables of anomalies for every degree. The earth's diameter was computed as 1600 *yojanas*, and planetary distances were derived from their proportionality to their respective revolution numbers in the *yuga* by assuming the linear velocity of each planet to be the same. Bailly believed in the high antiquity of Hindu astronomy, was struck by the elegance and simplicity of its methods and rules, and expressed the view that astronomy had originated in India and was later on transmitted to the Chaldeans and the Greeks.[10] Bailly's work immediately attracted the scholarly attention of European astronomical and mathematical circles. Pierre Simon Laplace, for example, showed that the Hindu value of 12°13′13″ as the apparent and mean annual motion of Saturn at the beginning of the Kali Yuga (3101 B.C.) computed from their tables, agreed closely with the value of 12°13′14″ determined according to modern methods.[11] John Playfair of the Edinburg University published a long review of Bailly's studies with appreciative comments inviting more intensive work on the subject of Hindu astronomy.[12] Although he later on entertained doubts about the high antiquity of Indian astronomy as asserted by Bailly he freely acknowledged the

impact of these early studies in following terms: "When the astronomical tables of India first became known in Europe the extraordinary light which they appeared to cast on the history and antiquity of the East made everywhere a great impression; and men engaged with eagerness in a study promising that mixture of historical and scientific research, which is, of all others the most attractive."[13] He advocated a systematic search for Sanskrit mathematical and astronomical works, all manner of descriptions and drawings of astronomical buildings (observatories) and instruments found in India, and actual observation of the skies in the company of Indian astronomers versed in their own system.

Samuel Davis on The Sūrya-Siddhānta and Jupiter's Cycle

These ideas and problems were already agitating the minds of other scholars. In India the Asiatic Society was recently founded (1784) precisely for carrying on researches of this kind into the antiquities, literature, history, sciences, arts, crafts and manufactures of the peoples of Asia in general and of India in particular. Shortly after the publication of Bailly's *Traité de l'Astronomie,* Samuel Davis in England procured, through Robert Chambers, a copy of the *Sūrya-siddhānta* with a good commentary. From the commentary he learnt of the existence of a large number of Sanskrit astronomical texts, e.g. the *Brahmasiddhānta* of the *Viṣṇudharmottarapurāṇa,* the *Paulastya-, Soma-, Vaśiṣṭha-, Ārya-, Romaka-, Parāśara-,* and *Ārṣa-siddhānta, Graha-lāghava, Sākalya Saṃhitā, Siddhāntarahasya, Makaranda-sāraṇi,* and a few others. He carried out a detailed analysis of the text, giving translations of a large number of rules, in his study published in the *Asiatick Researches,* Vol. II., which included the concept of *yuga, kalpa* and other divisions of time,—*Kali, Dvāpara, Tretā* and *Satya,* revolutions executed by each planet in a *Mahāyuga* of 4,320,000 years, the canon of sines, the model of eccentric circle for converting mean longitudes of planets into true longitudes. He noted variations in planetary motions in various texts and observed that discrepancies between textual calculations and actual observations were corrected from time to time by the method of *bīja* corrections. "Accordingly, Āryabhaṭa, Brahmagupta and others", he stated, "having observed the heavens, formed rules on the principles of former shastras; but which differed from each other in proportion to the disagreements, which they severally observed, of the planets with respect to their computed places."[14]

The canon of sines, of which Davis gave the tables in sines and versed sines with respect to radius equal to 3438', was needed, he clarified, for the computation of the equation of the mean to the true anomaly. The eccentric-epicyclic geometrical models were pressed into service in Hindu astronomy 'to account for the apparent unequal motion of the planets, which they suppose to move in their respective orbits through equal distances in equal times'. The whole computational procedure was clearly described with the help of eccentric circle diagrams for solar inequality and eccentric-epicyclic model for other planets.

With regard to the value of 24° as the obliquity of the ecliptic, Davis recalled Lagrange's work suggesting the slow variation of this constant with time and

expressed his view that this value true for around 2050 B.C. probably resulted from actual observation. Previously Bailly had also traversed the same ground and concluded that the Brāhmaṇas had determined it by observation about 4300 B.C. Davis also converted the Moon's mean distance in 51,570 *yojanas* from the Earth and arrived at 220,184 geographical miles or 64½ Earth-radius, somewhat wide of the mark from the modern value (226,000 miles at perigee and 252,000 miles at apogee). Davis' researches on the *Sūrya-siddhānta* proved extremely useful to later investigators, e.g. Burgess, and James Burgess did not exaggerate much when he characterized his 'On the astronomical computations of the Hindus' as 'a model of what such an essay ought to be'.[15]

Davis exhibited similar analytical approach in dealing with the subject of the twelve year cycle of Jupiter, which appeared in the third volume of the *Asiatick Researches* in 1792. This work was stimulated by an erroneous conclusion of William Marsden that Bṛhaspati's year coincided with the ordinary year.[16] Davis utilized materials from the *Āryabhaṭiya*, Varāhamihira, *Siddhānta-śiromaṇi* and *Jyotistattva*. In India a Jupiter's cycle of sixty years was widely followed. In this cycle the length of Jupiter's year is measured by the time taken by this planet to travel through one sign of the zodiac, which is 361d 0h 38m or with the *bīja* correction 361d 0h 50m. This value nearly agrees with the solar year. A cycle of sixty such years during which the planet undergoes five whole revolutions was adopted as a measure of time. A twelve-year cycle of Jupiter, that is, the time of one sidereal revolution of the planet was also adopted. Davis treated at some length of the sixty year cycle discussing rules given in the *Ārya-siddhānta* and the *Sūrya-siddhānta* for the computation of the planet's position in signs aι any given date. He also gave the name of each individual year in this cycle, e.g. 1. Vijaya, 2. Jaya, 3. Manmatha,...60. Nandana.[17]

William Jones On The Hindu Zodiac

The zodiac and the question of its antiquity attracted the attention of the noted orientalist William Jones who argued that it was an indigenous development.[18] Montucla, the celebrated French historian of mathematics expressed the view that the two divisions of the zodiac, one in twentyseven lunar mansions resembling the Arab *manāzils* and the other in twelve signs of the zodiac to mark the passage of the Sun through the celestial sphere, were possibly transmitted to India through Arab intermediaries. Jones tried to show 'that the Indian zodiac was not borrowed mediately or directly from the Arabs or Greeks, and since the solar division of it in India is the same in substance with that used in Greece, we may reasonably conclude that both Greeks and Hindus received it from an older nation'. Jones' arguments were based on information obtained from Brāhmaṇa astronomers and also from Śrīpati's *Ratnamālā* containing the names of twelve signs beginning with Meṣa and ending with Mīna and describing each sign, e.g. the ram, bull, crab, lion and scorpion representing five animals bearing these names, the pair showing a damsel playing on a *vīṇā* and a youth wielding a mace, the virgin standing on a boat in water holding in one hand a lamp and an ear of corn in the other, Tulā representing a balance held by a weigher, and so on. A diagram showing twelve signs in an outer circle, nine

planets (including Rāhu and Ketu) in an inner circle and Mount Meru with four cardinal directions in the centre was appended. On the basis of the same *Ratnamālā* Jones listed and described twenty-seven *nakṣatras* plus Abhijit, equivalent to Arab *manāzils;* these were headed by Aśvinī and terminated by Revatī. Comparing the members of the two systems and the number of stars associated with them,

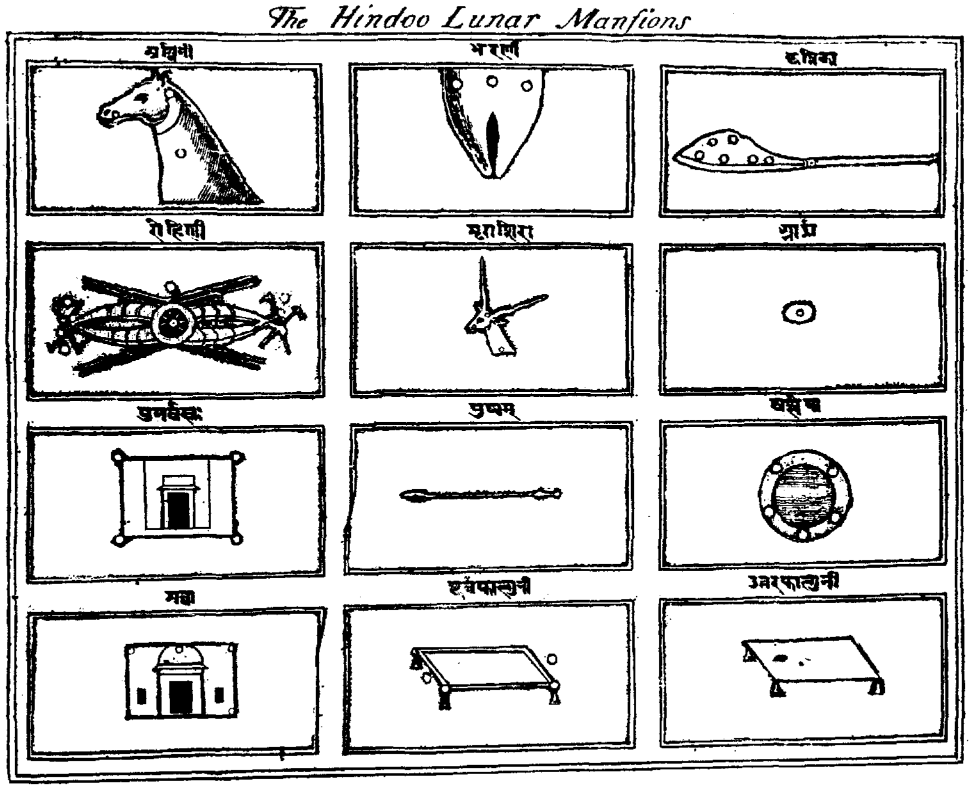


Fig. 3.1 Hindu Lunar Mansions.

he observed that there was hardly any agreement between the two systems. More importantly, twenty-seven *nakṣatras* were mentioned in Manu's Institutes, and he quoted his Brāhman informants that some of them were listed in the Vedas, 'three of which', he firmly believed from internal and external evidence, 'to be more than three thousand years old'. Thus started a great controversy on the antiquity of the zodiac and the priority of its invention which razed throughout the nineteenth century involving some of the best orientalists and historians of astronomy of the time. He also discussed the Hindu conception of the oscillation of the vernal equinox from the third of Mīna (Pisces) to the twenty-seventh of Meṣa (Aries) in the period of 7200 years, and suggested that equinox observations had been made as early as 1181 B.C.

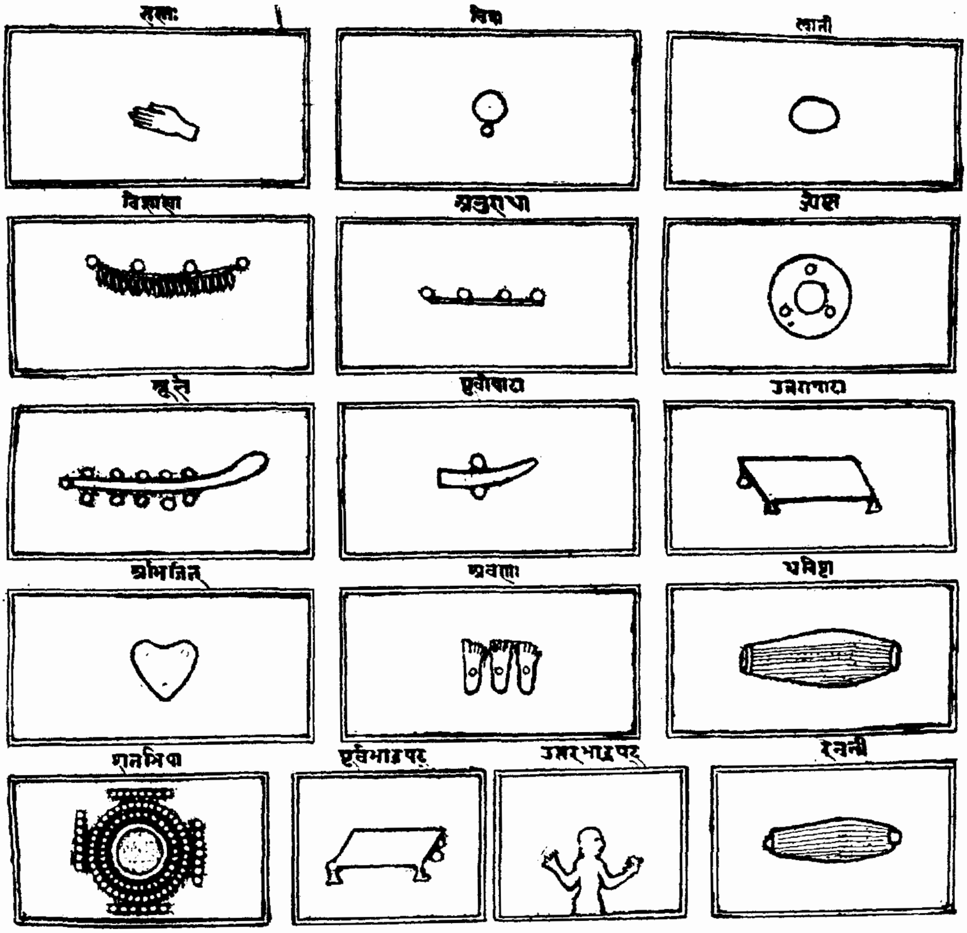


Fig. 3.1 (Contd). Hindu Lunar Mansions

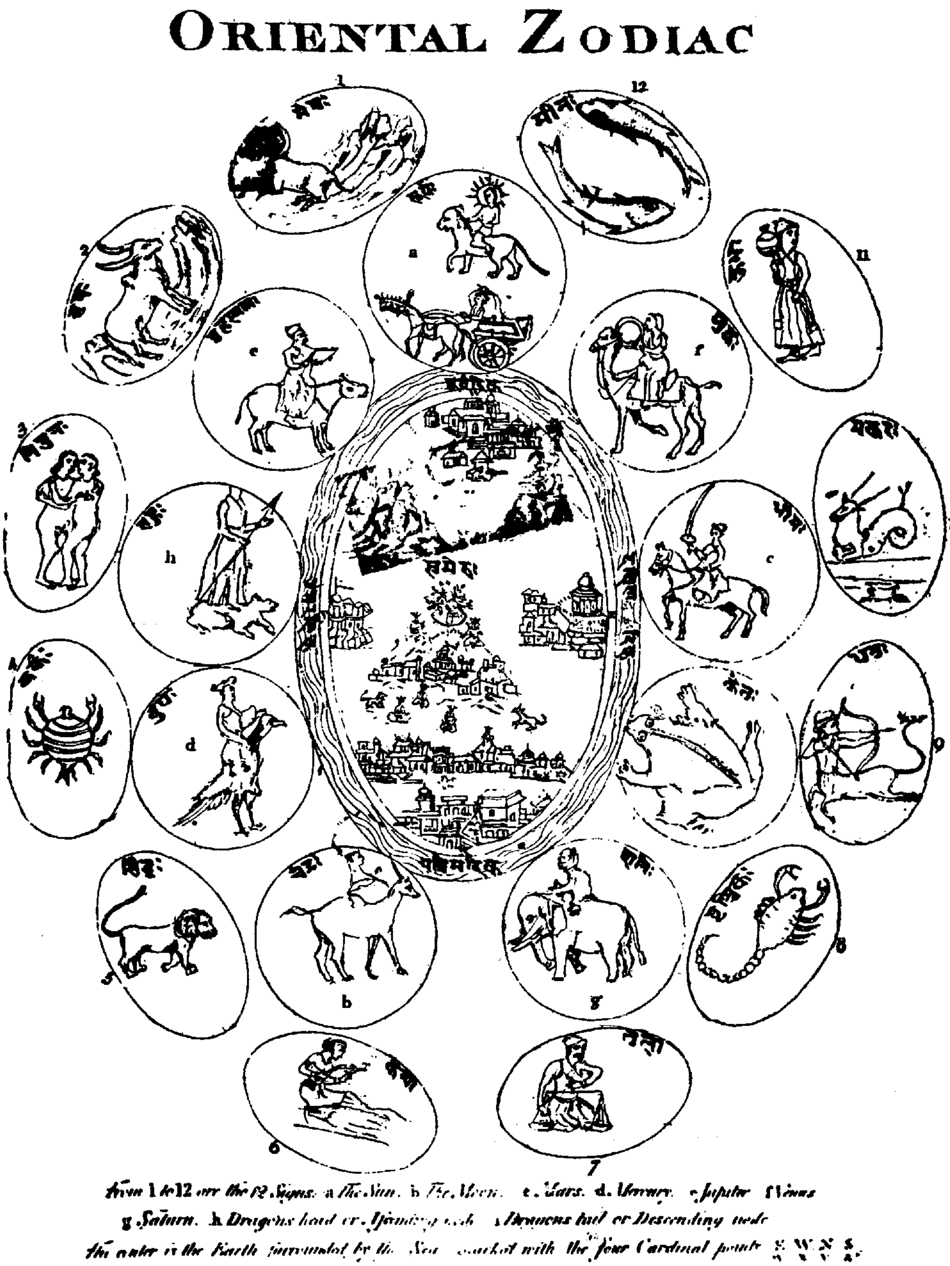


Fig. 3.2 Hindu Zodiacal Signs

John Bentley On The Sūrya-Siddhānta and its Dating

The high antiquity of Hindu astronomy advocated by Bailly, Playfair and Jones on the basis of their astronomical epochs and supposed observations millennia before the Christian era did not remain unchallenged for long. In 1799 John Bentley published in the *Asiatick Researches* a study on the antiquity of the *Sūrya-siddhānta* and the formation of the astronomical cycles contained therein.[19] By utilizing the internal evidence of the text and making calculations on the basis of its own elements Bentley concluded that the *Sūrya-siddhānta* could not have been composed earlier than A.D. 1091. The text indicated that at the commencement of the Kali Yuga era (February 17-18, 3102 B.C.) all the planets were in conjunction at the first point of the Hindu sphere, and it was asserted that such a phenomenon was then actually observed. Bentley determined from the ephemerides positions of the planets from the (first point of the) Hindu sphere. These positions together with the longitudes reckoned from the vernal equinox and the data given by Bentley and Bailly are shown in Table 3.1. It at once became clear that the planets were not in conjunction at the beginning of the Kali Yuga, and such long eras could not have been determined on the basis of observations. This point has been discussed recently by van der Waerden and others, to which a further reference will be made in what follows. Even if the mean positions were determined by actual observations at a more recent date the assumption of conjunction at the beginning of the Kali Yuga was destined to introduce serious errors after the lapse of long enough time.

Table 3.1. *Planetary positions on the midnight of February* 17-18, 3102 B.C. *for the meridian of Ujjayinī (Burgess (E), I.* 29-34, *notes).*

Planet	From beginning of Hindu sphere				Longitude			Bentley			Bailly		
		°	′	″	°	′	″	°	′	″	°	′	″
Sun	—	7	51	48	301	45	43	301	1	1	301	5	57
Mercury	—	41	3	26	268	34	5	267	35	26	261	14	21
Venus	+	24	58	59	334	36	30	333	44	37	334	22	18
Mars	—	19	49	26	289	48	5	288	55	19	288	55	56
Jupiter	+	8	38	36	318	16	7	318	3	54	310	22	10
Saturn	—	28	1	13	281	36	18	280	1	58	293	8	21
Moon	—	1	33	41	308	3	50	306	53	42	300	51	16
do apsis	+	95	19	21	44	56	42	61	12	26	61	13	33
do node	+	198	24	45	148	2	16	144	38	32	144	37	41

Later astronomers were aware of this difficulty and invented the method of *bīja* correction. By this correction the original revolution numbers of the planets were suitably altered so that the figures were still divisible by 4 and the system admitted

of operation with the lesser period, that is, one-fourth of the *Mahāyuga*. Davis incidentally discussed the *bīja* correction, but Bentley showed that such a correction was not introduced before the sixteenth century.

Bentley then argued that if the date of conjunction in the past was determined by working backwards resulting in greater computed errors in planetary positions it would be possible, by similar calculations, to arrive at a period when computed positions of the planets would more or less agree with observed values. If such a period could be found it would obviously answer for the period of composition of the treatise in question. Bentley went through the laborious exercise and gave his results in the form of a table (Table 3·2).

Table 3.2. *Bentley's table of errors in the positions of the planets as calculated for successive periods according to the Sūrya-siddhānta (seconds omitted).*

Planet	Kaliera 0 B.C. 3102	K 1000 B.C. 2102	K 2000 B.C. 1102	K 3000 B.C. 102	K 3639 A.D. 538	K 4192 B.C. 1091	When Correct
	° ′	° ′	° ′	° ′	° ′	° ′	A.D.
Mercury	+ 33 26	+ 25 10	+ 16 54	+ 8 38	+ 3 22	— 1 12	945
Venus	— 32 44	— 24 38	— 16 31	— 8 15	— 3 15	+ 1 14	939
Mars	+ 12 6	+ 9 27	+ 6 47	+ 4 8	+ 2 27	+ 0 58	1458
Jupiter	— 17 3	— 12 44	— 8 26	— 4 7	— 1 22	+ 0 41	906
Saturn	+ 20 59	+ 15 43	+ 10 28	+ 5 12	+ 1 50	— 1 45	887
Moon	— 5 53	— 3 51	— 2 9	— 0 53	— 0 19	— 0 1	1097
do apsis	— 30 11	— 23 10	— 16 8	— 9 6	— 4 36	— 0 43	1193
do node	+ 23 38	+ 17 59	+ 12 31	+ 7 3	+ 3 33	+ 0 32	1183

Averaging the results he arrived at A.D. 1091 as the possible date of composition of the *Sūrya-siddhānta*.

Bentley's approach was scientific and argument convincing but this could not be the sole criteria for determining the date of an astronomical work. He was misled by Śatānanda's statement in his *Bhāsvatī* that he was a disciple of Varāhamihira, believed that the latter was the author of the *Sūrya-siddhānta* and accordingly suggested that both the author and his work belonged to the eleventh century A.D. William Jones had already placed Varāhamihira around 499 A.D. Bentley's conclusion generated adverse crit'cism from scholars who had admired Bailley's work and did not like to see the latter work thus relegated to the background. An anonymous review of Bentley's work in the *Edinburgh Review* strongly criticised his conclusions and methods to which Bentley replied with equal vehemence and bitterness in the *Asiatick Researches*. Embittered by acrimonious controversy, Bentley refrained from publishing further studies, but continued to work on the historical

development of the subject by his method of errors. These studies vitiated somewhat by his attacks on those who disagreed with him were published posthumously in the form of a book *Historical View of the Hindu Astronomy* (1825).

Astronomical Observatories

The eighteenth century travellers, scholars, astronomers, and scientists of all sorts spending some time in India did not fail to take notice of the astronomical labours of Sawai Jay Singh and the observatories he built at Jaipur, Delhi, Ujjayini and other places. Joseph Tieffenthaler (1710-1785) who lived in India from 1743 to 1785 and wrote his *Descriptio India.* (French translation by Jean Bernoulli under the title *Description Historique et Geographique de l'Inde,* Berlin, 1786) left an account of the observatories at Delhi, Muttra, and Jaipur. The observatory built at Delhi by the Rajah more or less on the plan of the Jaipur observatory had an equinoctial dial, a gnomon and several other masonry devices for observations, of which the most conspicuous was a pair of round (cylindrical) buildings graduated in hours. In Jai Singh's time this part of Delhi was fairly an open country free from obstructions from high-rise buildings and monuments and suitable for astronomical observations. The Mathura observatory was built on a hillock commanding a vast plain all around. Its principal equipments were a gnomon built of brick and lime and representing the axis of the earth, an equinoctial dial, and several other intruments representing various sections of the sphere. The Jaipur observatory, Tieffenthaler wrote, was however the most remarkable of them all, 'un ouvrage tel qu'on n'en voit jamais vu dans ce contrées, et qui frappe d'étonnement par la nouveauté et la grandeur des instrumens'.[20] This observatory, like the others, was equipped with several masonry instruments, a large number of them being various sections of the celestial sphere, equinoctial dials, horizontal sun-dial, the quadrant, the gnomon and a number of astrolabes. The imposing gnomon, the axis of the earth, was seventy royal feet in height. Some of these instruments were superficially described more with a view to excite wonder than scientific curiosity.

Shortly after Tieffenthaler, W. Barker, Commander-in-Chief of the Bengal Army examined more critically and carefully the astronomical instruments of another observatory of Jai Singh at Benares.[21] About 1797 William Hunter, a surgeon with the British Army in India and an amateur astronomer studied the astronomical works of Jai Singh, reported on the contents of an astronomical *zij* dedicated to Emperor Muhammad Shāh, and gave a more detailed account of some of the instruments of his observatories. Jai Singh had studied Hindu astronomy and mathematics and his reputation in these sciences was so high that he was chosen by the Emperor to reform the calendar. In this assignment the astronomer king constructed a new set of tables, the *Zij Muhammadshāhi,* of the preface of which Hunter gave an elegant English translation side by side with the Persian original. About the observatory at Delhi, Jai Singh informs us in this preface that he 'constructed here (at Dehly) several of the instruments of an observatory, such as had been erected at Samarcand, agreeably to the Musulman books'. Furthermore: 'But finding that brass instruments did not come up to the ideas which he had formed of the accuracy,

because of the smallness of their size,...therefore, he constructed in Dar-ul-Khelafet Shah-Jehanabad, which is the seat of empire and prosperity, instruments of his own invention, such as *Jeypergās* and *Ram-junter* and *Semrāt-junter,* the semi-diameter of which is of eighteen cubits,...'[22] Besides the *Samrāṭ Yantra,* Hunter described several other instruments such as an equatorial dial provided with a gnomon in the middle and two concentric semi-circles on either side of it; an instrument named *ustuanah* designed to observe altitudes and azimuths of celestial bodies; an equatorial dial with a concave hemispherical surface 27′5″ in diameter, called the *shamlah;* and several others. The *shamlah,* representing the interior hemisphere of the heavens, was divided by fixed ribs of solid work and as many hollow spaces, the edges of which represented meridians at the distance of 15 degrees from one another.

INDIAN ASTRONOMY IN THE NINETEENTH CENTURY

Colebrooke on the Zodiac, Precession of the Equinoxes, Chronology of Astronomers

The appearance of Henry Thomas Colebrooke who combined the qualities of an able mathematician with those of an expert orientalist signalled a new period of fruitful activity in understanding the history of ancient Indian astronomy. Armed with sizable collection of Sanskrit mathematical and astronomical texts and commentaries, he reexamined the stellar zodiac question, the precession of the equinoxes, and the dating of the leading authors and commentators, apart from his major contributions to the elucidation of the mathematics of Brahmagupta and Bhāskara II.

Colebrooke revived William Jone's question regarding the antiquity of the stellar zodiac and particularly asked the question whether the Indian and the Arabian division of the zodiac had a common origin. He examined and considered the positions of the principal stars, *yogatārā,* of the *nakṣatras* and lunar mansions as given by the *Sūrya-siddhānta, Siddhānta Śiromaṇi (Marici), Grahalāghava,* Brahmagupta (as cited by Bhūdhara), besides the *Ratnamālā* previously utilized by Jones. He discussed the ancient Indian methods of observing the positions of stars with the help of an armillary sphere, as described in the *Sūrya-siddhānta,* and another method elaborated in the *Siddhānta Sundara.* Ptolemy had also used armillary spheres for astronomical observations, but by comparing the description of the Greek instrument as given in Nasir al-Dīn al-Ṭūsī's *Tahriru'l-majesti* with that of the Indian one as described in the *Siddhānta Śiromaṇi,* Colebrooke concluded that the two instruments differed in many details and the one was not the copy of the other.[23]

Each *nakṣatra* was then compared with the corresponding *manzil.* In the case of Aśvinī, for example, the *nakṣatra* comprises, according to Sanskrit texts, 'three stars figured as a horse's head; and the principal which is also the northern one, is stated by all ancient authorities, in 10°N and 8°E from the beginning of Meṣa'. The first Arabian *manzil,* Sharatān, 'comprises two stars of the third magnitude on the head of Aries, in lat. 6°36′ and 7°51′N and long. 26°13′ and 27°7′...' The principal star

in the two constellations is apparently the same. Likewise the Arabian *Dabarān* is identical with the Indian Rohiṇī. But such is not the case with Abhijit and *Ẕābiḥ*, where a total disagreement is noticed. From such comparisons he concluded that the Indian asterisms generally consisted of nearly the same stars which constituted the lunar mansions of the Arabians, but in a few instances they essentially differed. Likewise the similarities of figures and designations of the twelve signs of the zodiac with those of the Greek appear to suggest that the Hindus might have taken from the Greeks the hint of this mode of dividing the ecliptic; but 'if such be the origin of it,' remarked Colebrooke, 'they have not implicitly received the arrangement suggested to them, but have reconciled and adopted it to their own ancient distribution of the ecliptic into twentyseven parts.'[24] For many years to come Colebrooke's study constituted the chief source of information of the Indian *nakṣatras* vis-a-vis the Arabian *manāzil* till the controversy was further enlivened by the researches of Biot claiming greater antiquity for the Chinese *hsius*.

More importantly, Colebrooke recognized that Varāhamihira's *dreṣkāṇas*, used in his *Vihajjātaka*, were equivalent to the decani of European astrologers. The *dreṣkāṇa* is one-third of a sign to which is allotted a regent exercising planetary influence. Each sign of the Arabian zodiac is also similarly divided into three parts, each called a *wajeh*. This is an astrological concept which originated with the Babylonians and the Egyptians and passed on to the other countries,—Greece, India. The Greek decani were discussed in Manilius, Hephaestion, Firmicus, and Psellus, and the Sanskrit equivalent, Colebrooke thought, came from the same source (see Pingree's *Yavanajātaka* discussed later). 'In the present instance', he observed, 'Varāha Mihira himself, as interpreted by his commentator, quotes *Yavanas*...in a manner which indicates that the description of the *dreṣkāṇas* is borrowed from them'.[25] This commentator Bhattotpala and others frequently cited the name of one *Yavanācārya*, and Colebrooke suspected that under this name a Grecian or an Arabian author was probably intended. He even suggested that if the work attributed to him could not be recovered it would be worth-while to collect all passages in which Yavanācārya was cited to throw further light on this important point. David Pingree's recent works to which we shall refer in what follows shows how good Colebrooke's informed guess was.

Colebrooke followed up his work on the division of the zodiac by a study of the notion of Hindu astronomers concerning the precession of the equinoxes. He traced the precession idea in Bhāskara II's *Siddhānta-śiromaṇi (Golādhyāya)*, *Sūrya-siddhānta*, *Soma-siddhānta*, *Laghu-vasiṣṭha*, *Sākalya-saṃhitā*, *Parāśara-saṃhitā*, and a few other texts. Two ideas were current,—one the retrograde revolution of the equinoxes throughout the twelve signs, and the other a libration or oscillation of the two equinoxes about the fixed points with certain limits of degrees. Besides these two basically different ideas, there was also considerable divergence of opinion on the question of the rate of precession. The first idea of precession as a revolution through the twelve signs was advocated by Bhāskara II (*Golādhyāya*, c.b.V. 17 and 18) on the authority of Muñjāla; the *krāntipāta*, the intersection of the ecliptic and the equinoctial circles is declared to undergo 30,000 revolutions in a *kalpa*. Colebrooke then notices passages in the *Sūrya-*

siddhānta, Soma-siddhānta, Laghu-vasiṣṭha and *Śākalya-saṃhitā*, which also teach a motion of the equinoxes, such motion being of the nature of a libration within the limits of 27 degrees east as well as west from the Hindu fixed points (beginnings of Aries and Libra).[26] These librations take place at the rate of 600,000 in a *kalpa*. The *siddhāntas* of Parāśara and Āryabhaṭa also advocate similar doctrine but their revolution values are slightly less. As to limits of libration Āryabhaṭa gave 24° east and west of the fixed point. Brahmagupta was silent about the precessional motion. As to the two views, the majority of Indian astronomers adhered to the libration theory of the *Sūrya-siddhānta*.

Colebrooke then discussed the libration or trepidation theory as developed by the Arab astronomers (Arzacel, Thabit ibn Qurrah), the limits in degrees of oscillations and their periods. Although somewhat out of place in this paper some of the special features of the eccentric-epicyclic models of planetary motions were pointed out. The eccentric model had already been used by Hipparchus, and Apollonius was credited with the invention of the geometry of epicycle on a deferent. Ptolemy adopted the same models to account for planetary inequalities, but introduced the new concept of the 'equant' which is absent in the Hindu treatment. What is striking, Hindu astronomers sought better accuracy by giving 'an oval form to the eccentric or equivalent epicycle, as well as to the planet's proper epicycle'.[27]

Colebrooke's *Algebra, with Arithmetic and Mensuration, from the Sanskrit of Brahmegupta and Bhāscara* was mainly concerned with the exposition of mathematics as dealt with by these two celebrated authors. But the dissertation with which he prefaced the work contained many valuable glimpses on Indian astronomy as also a critical discussion of the dating of ancient astronomers and their commentators. In Colebrooke's time Āryabhaṭa was known through references contained in Brahmagupta's works and those of Bhāskara II's scholiast Gaṇeśa and a few other commentators. Āryabhaṭa was also known to the Arabs under the abbasid Khaliphs as 'Arjabahar' or 'Arjabhar'. Piecing together such scattered and scanty information on this ancient astronomer Colebrooke suggested that Āryabhaṭa preceeded Brahmagupta and Varāhamihira by several centuries and further that, if Varāhamihira lived at the beginning of the sixth century A.D. Āryabhaṭa could have written 'as far back as the fifth century of the Christian era and was almost as ancient as Diophantus.[28] In all this he was guided to some extent by the chronology collected by William Hunter from the astronomers of Ujjayinī, which placed some of the ancient Hindu astronomers as follows: Varāhamihira—A.D. 505-6; Brahmagupta—A.D. 628–9; Muñjāla—A.D. 854; Bhaṭṭotpala—A.D. 890; Bhāskara II—A.D. 1150-1. Colebrooke also correctly noticed Āryabhaṭa as the author of an astronomical system and founder of a sect in that science, mentioning, in particular, his view about the diurnal revolution of the earth, his epicyclic planetary theory and his theory of eclipses disregarding imaginary dark planets of the mythologists and astrologers.[29]

Colebrooke possessed a manuscript copy of Brahmagupta's *Brāhmasphuṭasiddhānta*, which he interpreted as an emended text of an earlier system known as the *Brahma-siddhānta* which had ceased to agree with astronomical observations. He gave the date

of his work as A.D. 628 corresponding to Śaka 550. Although Brahmagupta's mathematics was dealt with in detail in his *Algebra,* his various astronomical topics were briefly summarized in the Dissertation.[30] Finally Colebrooke provided a wealth of information about the scholiasts of Bhāskara, many of whom were well-known authors and commentators of astronomical works during medieval times,—Gangādhara, Jñānarāja, Sūryadāsa, Nṛsiṃha, Lakṣmīdāsa, Gaṇeśa, Ranganātha, Munīśvara and Kamalākara.

John Warren on the Tamil Reckoning of Time

Lt. Colonel John Warren of the Trigonometrical Survey of India prepared, during the first quarter of the nineteenth century, a number of memoirs on the various modes according to which astronomers of India, specially of the southern provinces, used to divide time. Although his main purpose was to explain the Indian calendars, and not to provide a critical exposition of Indian astronomy, his work proved useful in understanding 'the present extent of our knowledge in Hindu astronomy in these southern provinces'. The main discussion and tables centred round three distinct subjects, e.g. (a) Tamil solar year on the authority of the *Āryasiddhānta,* (b) luni-solar astronomical year and the calendar of the Telengana countries according to the *Sūrya-siddhānta,* and (c) the Muhammadan calendar on the Arabic system. Accordingly, the whole book entitled *Kāla Saṅkalita* (a compendium on the doctrine of time) comprises four memoirs and an appendix containing several explanatory notes and tables. The first memoir discusses the mean solar sidereal year *(madhyama soara māna)* used in Tamil land. The second deals with the theory and construction of the luni-solar astronomical year *(siddhānta candra māna),* on which rests the whole fabric of Hindu astronomy; here the computation of different elements is explained on the basis of the rules given in the *Sūrya-siddhānta* and at the same time the problems of the gnomon, and applications of trigonometry in finding right ascension, declination, longitude, zenith distance and amplitude of stellar bodies are fully demonstrated. The Indian cycle of sixty years is the subject of treatment of the third memoir, in which three different methods,—the first according to the *Sūrya-siddhānta,* the second on the basis of an astrological work current in the northern provinces of Bengal and the third followed in Telengana countries, are explained. The fourth memoir is devoted to the construction of the Muhammadan lunar year and the compilation of a general table showing the commencement of every year of the Hegira from the origin of the era to the lunar year corresponding to A.D. 1900.[31]

An interesting feature of the work is an exposition of the solar or *vākyam* process applied for the computation of eclipses. The elements from which the *vākyam* rules and tables are constructed are extracted from the *Ārya-siddhānta.* 'The most remarkable difference between the *vākyam* process and that of the *Sūrya-siddhānta*', Warren explained, 'is that the computations of the former are directly for the apparent, without previously obtaining the mean places of the asters, and that these refer to the time of sun rising, instead of mean midnight, as is directed in the *Sūrya-siddhānta*'.[32]

C. M. Whish On Indian Zodiac

That the concept of dividing the zodiac into twelve signs was influenced by the Greeks was already suspected by Colebrooke despite William Jone's assertion in favour of an indigenous origin. C. M. Whish utilized materials from Varāhamihira and a commentary *Prabhodana* on Śrīpati's *Ratnamālā,* in which one Yavaneśvara is again mentioned, to show that a large number of technical terms typical of Greek astrological literature found their way into Sanskrit astrological works. As an example, he cited the names of the twelve signs of the zodiac as follows: Kriya (*kpios*)—Aries; Tāvuri or Tāmbiru (*Tavpos*)—Taurus; Jituma (*Δiδvμos*)—Gemini; Kulira or Karka (*Kapkivos*)—Cancer; Leya (*Λεωv*)—Leo; Pāthona (*παpθεvos*)—Virgo; Jūka (*Ζvγov*)—Libra; Kaurypa (*Σkopπios*)—Scorpio; Taukṣika (*Toξoτηs*)—Sagittarius; Ākokera (*'Avγokεpωs*)—Capricornus; Hṛdroga (*Υδpoχoos*)—Aquarius; Ittha (*'Iχθvs*)—Pisces.[33] Likewise Varāha's *Horā śāstra* transliterates some of the Greek planetary names as follows: Heli (*"Hλios*) for the Sun, Himna (*'Epμηs*) for Mercury, Āra (*"Apηs*) for Mars, Koṇa (*Kpγvs*) for Saturn, Jyaus (*Ζεvs*) for Jupiter and Āsphujit (*'Aφpo δiτη*) for Venus. Apart from the names of the zodiac and a few planets, several Greek terms used in geometry, astronomy and astrology were adopted almost without change in Sanskrit writings, of which the following are a few examples:—āpoklima—declination; dreṣkāṇa, dṛkāṇa, dṛkkāna or drekkāna—the chief of ten parts (out of thirty) of a sign, already discussed by Colebrooke; durudharā—the 13th yoga; harija—horizon; hibuka—the 4th lagna or astrological house; horā—hour, 24th part of a day; jāmitra—diameter, the 7th house; kendra—anomaly, argument of an equation; koṇa—angle; trikoṇa—triangle; liptā—a minute of arc; meṣuraṇa—meridian; panapharā—rising, also 2nd, 5th, 8th and 11th houses. Etymologically none of these words appear to be of Sanskrit origin. Weber who also went over these terms expressed the view that these were used in the same sense in which Paulus Alexandrinus applied them in his *Eisagoge.*[34]

Lancelot Oilkinson and Bāpudeva Śāstrī's Study Of Bhāskara II's Astromomy, Jervis on Indian Astronomy, and Hoisington's Oriental Astronomer

Between 1830 and 1850 some important contributions to the study of ancient Indian astronomy included the translation by Lancelot Wilkinson and Bāpūdeva Śāstrī of part of Bhāskara II's *Siddhānta-śiromaṇi,* Capt. J. B. Jervis' papers on metrology and calendars, J. B. Biot's work on the antiquity of lunar mansions, particularly of the Chinese *hsius* and the Indian *nakṣatras,* and Rev. Hoisington's work on Tamil astronomy. Wilkinson who spent some time in Sehore in Central India was a great enthusiast of Indian astronomy and advocated the teaching of science in schools with the help of Sanskrit text books like Bhāskara's *Siddhānta-śiromaṇi.*[35] In this connection he gave a translation of portions of the text. Later on, with the assistance of Bāpudeva Śāstrī, he published the *Golādhyāya* section of the *Śiromaṇi* and subsequently a translation with notes. A Marathi translation of the work *Siddhānta-śiromaṇi-ṭikā* had already appeared from Bombay in 1837 as had done the same work with the commentary *Siddhānta-śiromaṇi-prakāśa* from Madras in the same year. In

1844, E. Roer published a Latin translation of Bhāskara II's *Gaṇitādhyāya* in the *Journal of the Asiatic Society of Bengal.*[36]

Capt. J. B. Jarvis' work on Indian metrology drew largely upon Indian astronomical texts, e.g. *Bṛhat Cintāmaṇi* and also dealt with Hindu *Pañcāṅgas* (calendar). Rev. H. R. Hoisington's *The Oriental Astronomer* comprised a Tamil text on calendrical astronomy and a translation and proved useful in understanding the computational methods followed in Indian almanacs current in Tamil countries. Biot gave a good summary of the work in his *Etudes sur l'astronomie indienne et sur l'astronomie chnoise.*[37] Biot had already stirred the scholarly world by his views on the Chinese origin of the lunar mansions, expressed in a series of papers originally published in the *Journal des Savants* in 1840 and 1845 and initiated a controversy on the question of the priority of invention of the stellar zodiac which came to a head in the sixties of the last century, to which we shall revert in what follows.

TRANSLATION OF THE SŪRYA SIDDHĀNTA

By the middle of the century it became possible to form on the basis of pioneering studies by men like Le Gentil, Bailly, Davis, Jones, Colebrooke, Bentley and others, a good ideas as to the contributions of ancient Hindus to the science of astronomy. These contributions established the authority of the *Sūrya-siddhānta* as the astronomical work *par excellence,* accepted unanimously by all the leading *jyotiṣa* schools in India. Yet the entire work, in original Sanskrit text as well as in English translation, was not available for easy reference and study. In 1859, the Asiatic Society of Bengal whose publication, the *Asiatick Researches* had already provided the forum for scholarly discussions on the subject, partially fulfilled this need by publishing the Sanskrit text with a commentary *Gūḍhārthaprakāśikā* under the editorship of Fitz Edward Hall and Bāpudeva Śāstrī in the *Bibliotheca Indica* series.[38] The following year appeared the long awaited English translation of the text with copious explanatory and historical notes of inestimable value. The translator Rev. Ebenezer Burgess was a devoted American missionary who lived in India in the Bombay Presidency from 1839 to 1854 and was attracted to the Sanskrit astronomical literature in connection with a project concerning 'the preparation, in the Marathi language, of an astronomical text-book for schools'. He quickly realized that 'there was nothing in existence which showed the world how much and how little the Hindus know of astronomy, as also their mode of presenting the subject in its totality, the intermixture in their science of old ideas with new, of astronomy with astrology, of observation and mathematical deduction with arbitrary theory, mythology, cosmogony, and pure imagination'. This deficiency, he thought, could well be supplied by the translation and detailed explication of a complete treatise of Hindu astronomy. As the project took shape the American Oriental Society expressed interest in the work, and its Committee of Publication extended every cooperation and assistance towards the completion of the manuscript. The distinguished orientalist Prof. Whitney was associated with the work to enrich the translation with notes and additional matter of value. Hubert A. Newton, Professor of Mathematics at the Yale College, New Haven supplied the mathematical notes

and demonstration as also several comparative studies of Hindu and Greek astronomical questions. Thus was accomplished, as Biot remarked, a noble work of scholarship of positive science, a very difficult work calling for indefatiguable devotion, which almost spared nothing to facilitate an intimate understanding of the mysteries of the astronomical science of the Hindus.[39]

In addition to the notes in full utilization of previous studies, the translation was appended with additional notes and tables, calculation of eclipses, and a stellar map. As to the manuscripts relating to astronomical works made available to Burgess by the Pundits of the Sanskrit College at Puna, we are informed of the following 19 *siddhāntas*, e.g. *Brahma, Sūrya, Soma, Vaśiṣṭha, Romaka, Paulaśtya, Bṛhaspati, Garga, Vyāsa, Parāśara, Bhoja, Varāha, Brahmagupta, Siddhānta śiromaṇi, Siddhānta sundara, Tattva-viveka, Sārvabhauma, Laghu-Ārya,* and *Bṛhat-Ārya.* Nine *siddhāntas* mentioned in the Sanskrit encyclopaedia, *Śabdakalpadruma,* were also referred to, viz. *Brahma, Sūrya, Soma, Bṛhaspati, Garga, Nārada, Parāśara, Paulastya,* and *Vaśiṣṭha.* Burgess divided these works into four categories, e.g. (1) *siddhāntas* revealed by superhuman beings,—Brahma, Sūrya, Soma, Vṛhaspati, Nārada; (2) works attributed to sages,—Garga, Vyāsa, Parāśara, Vaśiṣṭha etc; (3) works by ancient authors whose dates in some cases might be uncertain,—Ārya, Varāha, Brahma, Romaka, Bhoja; and (4) later texts of known date and authorship, but of less independent and original character,—*Siddhānta śiromaṇi, Siddhānta sundara* of Jñānarāa, *Grahalāghava, Siddhānta tattvaviveka* etc.

Burgess maintained that, as far as the mean motions of the planets, the date of the last general conjunction and the frequency of its recurrence were concerned, the system of the *Sūrya-siddhānta* agreed with that of the *Śākalya-saṃhitā,* the *Soma*—and *Vasiṣṭha-siddhānta,* following the view of Bentley. *Pauliśa*—and *Laghu-Ārya-siddhāntas* also follow a more or less similar system. Planetary revolution numbers in an age sometimes differ from those of the *Sūrya-siddhānta,* but this difference is by a number which is a multiple of four. *Siddhānta-śiromaṇi* and other works, following the authority ot Brahmagupta, have somewhat different system. The starting point of planetary motions is ζ Piscium at the commencement of the Æon or *Kalpa* (4,320,000,000) so that they are again in conjunction at the end of it. Even then all systems take particular care that all planets are also in conjunction or nearly so at the beginning of the *Kali Yuga* at the moment of mean sun-rise at Laṅkā. This is illustrated by a table of mean places of planets at 6. A.M. at Ujjayinī on February18, 3102 B.C.

Burgess and Whitney believed that the scientific aspects and parameters of the *Sūrya-siddhānta* were based on Greek astronomical sources. Observational astronomy in India had not been developed to such an extent as to make possible generation of data indispensable for such computations and improvements upon them from time to time. In their view, Hindu astronomy as 'an offshoot from the Greek, planted not far from the commencement of the Christian era, and attaining its fully developed form in the course of the fifth and sixth centuries'. This transmission probably took place in connection with the lively maritime trade between the Western coast of India

and Alexandria in the first centuries of the Christian era. Had the transmission taken place by way of Syrian, Persian and Bactrian Kingdoms, Rome would not have so prominently featured in the astronomical literature. Whitney and Burgess, however, failed to notice in the *Sūrya-siddhānta* or other authoritative texts traces of Ptolemy's improved system and explained this on the ground that the transmission had probably taken place before the time of Ptolemy. The discovery of the manuscripts of *Pañcasiddhāntikā* by Varâhamihira and their study by G. Thibaut and Sudhakara Dvivedi, as we shall see in what follows, have thrown further light on this question by making available a number of astronomical texts typical of the transitional period.

Controversey about the Origin of Lunar Mansions

We have seen that the Indian stellar zodiac had been the subject of an important discussion among the orientalists since the time of William Jones. Although the Greek origin of the division of the zodiac into twelve signs was generally admitted, the orientalists were almost unanimously agreed about the Indian origin of the *nakṣatras* or twenty-seven lunar mansions. In 1840, J. B. Biot, a member of the French Academy of Sciences published in the *Journal des Savants* a study on ancient Chinese astronomy in commemoration of the distinguished sinologist Ludwig Ideler,[40] in which he endeavoured to show that the lunar mansions had their origin in China and that the Indian *nakṣatras* were adopted from the Chinese system for astrological purposes. To summarize Biot's conclusions, (1) the system was first established in China around 2350 B.C. and completed and perfected about 1100 B.C.; (2) originally the Chinese *hsiu* stars were a series of single stars spread more or less along the equator, without any relation with the moon, and employed for determining meridional transits of heavenly bodies; (3) eastern nations, including India, borrowed the system from China, distorted it, and applied it to demarcate the ecliptic, by utilizing a few chance coincidences although the system was never intended for such application. In his *Études sur l'astronomie indienno* etc. Biot further observed: 'I was led, twenty years since, to recognize, and to demonstrate by palpable proof, that this singular institution, which enters into the general system of the Indian astronomy as a thing foreign to it, has its root and its explanation in the practical methods of the ancient Chinese astronomy, whence the Hindus derived it, altering its character, in order to employ it in astrological speculations'. He also attacked the indianists for their deficiency in the knowledge of astronomy and mathematics which he considered indispensable for a correct appraisal of a scientific and technical subject of this nature.

Biot's studies and remarks attracted wide attention. In Germany, the distinguished indologist Lassen found Biot's views acceptable, but Weber who was then deeply immersed in Vedic studies found these claims highly exaggerated and prepared for a fitting reply to Biot's views. Weber's efforts resulted in the publication of his two celebrated papers under the title 'Die vedischen Nachrichten von den Naxatra (Mondstationen)' published in the *Abhand. der Königl. der Wissenschaften,* in two parts, in 1860 and 1862 respectively. In the first part, devoted to historical introduction, Weber summarized Biot's opinion about the Chinese origin of Indian

nakṣatras, and then examined the whole series of questions connected with the controversy, e.g. the chronologies of Schu-King, Schi-King, Eul-ya, Yue-ling, Tcheou-li etc.; the beginning of the 28 *hsiu* stars from the time of Lu-pou-ouey; the series beginning with the *hsiu* star *Kio* and not with *Mao;* the more ancient nature of the Indian *nakṣatra* series headed by Kṛttikā, consideration of the question whether the Chinese *hsius* could not on the contrary be borrowed from Indian *nakṣatras* ystem; the relation between the system obtaining in West Asia and China; traces of an old Babylonian system of lunar stations in the Fihrist and in an ancient Harranian festival; the differences between the Indian *nakṣatra* and the *hsiu-manāzil* systems; the Indian origin of the *manāzil* series as well as of the system of lunar stations mentioned in the *Bundehesh.*

In the second part of his *Nachrichten*, Weber considered in detail the development of the *nakṣatra* system in the *Saṃhitās* and *Brāhmaṇas*, concentrating on the following topics, e.g., general examination of the significance of *nakṣatra* in the Vedas; the use of the word '*nakṣatra*' in the sense of star as well as in the special sense of lunar mansion; the recognition of twenty-seven *nakṣatras;* the legend of 27 *nakṣatras* as wives of the Moon; 27 *nakṣatras* marking 27 sidereal days constituting the Moon's sidereal month; the use of the system in the *Lāṭyāyana-sūtra* and *Nidāna-sūtra*, recognizing several types of years; the *nakṣatra*—rituals of the Brāhmaṇa period such as the *agnyādhānam, punarādheam, āgrayayṇam, agnicayanam, nakṣatreṣṭakās* etc.; the later development of the system of 28 *nakṣatras* with the inclusion of Abhijit.

The word '*nakṣatra*' has been traced in the earliest Vedic texts and explained from Sanskrit etymological considerations. [41] An older form '*Kṣatrāṇi*' is met with in the *Śatapatha Brāhmaṇa* (2, 1, 2, 18, 19). In the *Taittirīya Brāhmaṇa* (2, 7, 18, 3) and *Atharvaveda* (7, 13, 1), the word is no longer '*kṣatra*', but '*na-kṣatra*'. In explaining '*nakṣatra*', Pāṇini refers to the irregular construction of the word '*na-kṣatra*' from the root $\sqrt{}$*kṣar* (meaning 'fliessen', 'to flow'). According to another etymological consideration $\sqrt{}$*nakṣ* signified 'the changing' (die Wandelnden) in which sense the word was used in the *Śatapatha Brāhmaṇa (tan nakṣatraṇāṃ nakṣatratvam).*

Among the various uses found of the word in the Vedas, the most general use appears to be to signify a heavenly object or source of light and illumination. It is no wonder that the Sun itself should be described as a star (ein Gestirn) as the *Ṛgveda* (7, 81, 2) does *(nakṣatram arkivat)*. Its use in the special sense of a lunar mansion also developed during the period of the *Saṃhitās* and the *Brāhmaṇas*. This is particularly so in connection with the three *Yajus* texts where '*nakṣatra*' is used in this special sense. The *Śatapatha Brāhmaṇa* (9, 4, 1, 9) clearly states that the Moon dwells with the *nakṣatra* as a Gandharva does with the Apsarās (Der Mond stieg mit den naxatra, (wie) ein Gandharva mit Apsarasen). The *Saḍviṃśa Brāhmaṇa* (10, 5, 4, 17) echoes the same idea when it says—*tasmāt somo rājā sarvāṇi nakṣatrāṇi upaiti, somo hi retodhāḥ,* that is, 'thereupon the king Soma lives (in turn) with all the *nakṣatras;* and he is really the seedsman (samenhaltend). From these rudimentary ideas developed the well known Brāhmaṇa legend of the Moon-god Soma refusing to live with all the *nakṣatras*, daughters of Prajāpati, whereupon the latter withdrew his daughters. Weber described

the legend as given in the *Kāṭhaka Saṃ.* (11, 3) as follows: "Prajāpati gave away to king Soma his daughters, the *nakṣatras*. But Soma lived only with (the *nakṣatra*) Rohiṇī. Thereupon the others who were thus deprived of his visit went to their father and complained to him of their plight. Prajāpati decided not to send his daughters back to the Moon and spoke to him (Moon) as follows, " 'You (promise to) live with all of them in the same way (*samāvat*, gleichmässig) then shall I again send them back to you'. Thereafter the Moon lives equally with all the *nakṣatras*."[42]

The *nakṣatras* also occupied an important place in several Vedic ceremonies. These ceremonies usually started with the *agnyādhāna*, that is, with the first construction of the two sacred household fires, e.g. the *gārhapatya* and the *āhavaniya*, usually during new or full moon, and were associated with *nakṣatras* such as Kṛttikās, or Rohiṇī or Mṛgaśīrṣa (*Śat. Br.* 2, 1, 2, 1, ff.). Another ceremony known as *punarādheyam* was to be observed at the double-starred *nakṣatra* Punarvasū (*etad vai punarādheyasya nakṣatraṃ yat punarvasū*, *S.TS.* 1, 5, 1.4).

Thus in India the *nakṣatra* system was firmly established in the period of the *Saṃhitās* and the *Brāhmaṇas*. When one considers the order and the beginning of the series, the identities between a limited number of stars, dissimilarities among the others, the Chinese *hsius*, Weber argued, corresponded in all probability to one of the latest stages of development of the Indian *nakṣatras*. About the changing character of the *nakṣatras*, he mentioned the case of Kṛttikā which sometimes comprised six and sometimes seven stars, the Greeks having a tradition of seven stars including a lost sister. Rohiṇī or Aldebaran was sometimes supposed to be formed of one bright star, and sometime described as including ξ Hydrae and the little group of five stars constituting the asterism Āśleṣā. For Abhijit Weber noticed the position as described in the *Taittirīya Brāhmaṇa* totally different from what obtained in the astronomical *siddhāntas*.

Weber placed some importance to the number of *nakṣatras* being sometimes given as 27 and sometimes as 28. He held that the groups were originally twenty-seven, and became twenty-eight later on with the addition of Abhijit. Thus in the various recensions of the Black Yajurveda,—*Kāṭhaka* (39, 13), *Taittirīya Saṃ.* (4, 4, 10, 1—3) and *Taittirīya Brāhmaṇa* (1, 5, 1, 1—5), 27 *nakṣatras* only are mentioned. The same number 27 is met with in the *Śatapatha Brāhmaṇa* (10, 5, 4, 5), *Pañcaviṃśa Brāhmaṇa* (23, 23), and *Kauṣitaki Āraṇyaka* (2, 16). The earliest record showing 28 *nakṣatras*, with Abhijit, is *Taittirīya Brāhmaṇa* (1, 5, 1, 3).[43]

Weber also touched upon some traces of old Babylonian tradition in respect of lunar mansions in Arabic literature and relations between West Asian and Chinese cultures. He noticed one such trace in the *Fihrist* recording an ancient Harranite custom. The Harranites followed a 27-day Moon month, and on the 27th day of such a month they observed the practice of visiting their holy temple and offering food and drink to the Moon-god. Another trace concerns the use of the word 'mazzaloth' in expression like 'the mazzaloth and all armies in the sky ("der mazzalloth

und alles Heeres am Himmel") in King Josias (II. Reg. 23, 5). By an interesting philological exercise Weber proved that the word meant a 'zodiacal portrait' ("zodiacal bild"), possibly a special class of stars to mark the stations of the Moon in its periodic motion through the skies, and in time became transformed into *manzil* (pl. *manāzil*) of the Arabs, which found a place in the *Qu'rān* itself. We reproduce below a table prepared by Weber to show the correspondence of *nakṣatras* with the *hsius* and the *manāzil.*

Nakṣatra	*Manāzil*	*Hsiu*
1. Aśvinī, β, γ Ariet	1. Sharaṭān, like *nakṣ*	16. Leu, β Ariet
2. Bharaṇī, 35, 39, 41, Ariet	2. Buṭain, like *nakṣ*	17. Oei, 35 Ariet
3. Kṛttikā, η Tauri	3. Ṭuraiyā, like *nakṣ*	18. Mao, like *nakṣ*
4. Rohiṇī, α, θ, δ, ϵ Tauri	4. Dabarān, like *nakṣ*	19. Pi, ϵ Tauri
5. Mṛgaśiras, λ, φ_1, φ_2 Orionis	5. Haq'a, like *nakṣ*	20. Tse, λ Orionis
6. Ārdrā, α Orionis	6. Han'a, η, μ, ν, γ, ξ Gemin	21. Tsan, δ Orionis
7. Punarvasū, β α Geminorum	7. Ḍirā, like *nakṣ*	22. Tsing, μ Geminorum
8. Puṣya, υ, δ, γ Cancri	8. Naṭra, γ, δ Cancri and Praesepe	23. Kuei, υ Cancri
9. Āśleṣā, ϵ, δ, σ, η, ρ Hydr	9. Ṭarf, ξ Cancri, λ Leonis	24. Lieu, δ Hydr.
10. Maghā, α, η, γ, ζ, μ ϵ Leon	10. Jabha, like *nakṣ*	25. Sing, α Hydr.
11. Pūrvaphālgunī, δ, θ Leon	11. Zubra, like *nakṣ*	26. Chang, ν_1 Hydr.
12. Uttaraphālgunī, β, 93 Leon	12. Ṣarfa, β Leon	27. Y, α Crateris
13. Hasta, δ, γ, ϵ, α, β Corvi	13. 'Awwā, β, η, γ, δ, ϵ Virgin	28. Chin, γ Corvis
14. Citrā, α Virgin	14. Simāk, like *nakṣ*	1. Kio, like *nakṣ*
15. Svātī, α Bootis	15. Ghafr, i, κ, , λ Virgin	2. Kang, κ Virg.
16. Viśākhā, ι, γ, β, α Libr.	16. Zubânay, like *nakṣ*	3. Ti, α_2 Libr.
17. Anurādhā, δ, β, π Scorp.	17. Iklīl, like *nakṣ*	4. Fang, π Scorp.
18. Jyeṣṭhā, α, σ, τ Scorp.	18. Qalb, α Scorp	5. Sin, σ Scorp .
19. Mūla, λ, υ, κ, ι, θ, η ζ μ Scorp.	19. Saula, λ, υ Scorp.	6. Uei, μ_2 Scorp.
20. Pūrvāṣāḍhā, δ, ϵ Sagitt.	20. Na'āyim, γ_2, δ, ϵ, η, ϕ, σ, τ, ζ Sagitt.	7. Ki, γ_2 Sagitt.
21. Uttarāṣāḍhā, σ, ζ Sagitt.	21. Balda, π Sagitt.	8. Teu, ϕ Sagitt.
22. Abhijit, α, ϵ, ζ Lyr	22. Sa'd aḍ-ḍābih, α, β Capricorni	9. Nieu, β Capric.

23. Śravaṇa, α, β, γ Aquil	23. Sa'd Bula, ϵ, μ, ν Aquar.	10. Nu, ϵ Aquar.
24. Śraviṣṭhā, β, α, γ, δ Delphin	24. Sa'd as—Su'ūd, β, ξ Aquar.	11. Hiu, β Aquar.
25. Śatabhiṣaj, λ Aquarii	25. Sa'd al—Akhbiya, α, γ, ζ, η Aquar.	12. Goei, α Aquar.
26. Pūrvabhādrapadā, α, β Pegasi	26. First Fargh, like *nakṣ*	13. Che, α Pegasi
27. Uttarabhādrapadā γ Pegasi, α Andromedae	27. Second Fargh, like *nakṣ*	14. Pi, γ Pegasi
28. Revatī, ζ Piscium	28. Baṭn al-Ḥūt β Andromedae etc.	15. Koei, ζ Andromedae

In volume 8 of the *Journal of American Oriental Society,* William D. Whitney critically compared the opinions and arguments of Biot and Weber, and put forward his own suggestions. While noticing the two systems of 28 and 27 *nakṣatras,* Biot had described the former as the 'ancient' and the latter 'modern' *nakṣatra,* Whitney showed that such a distinction was uncalled for and had 'no foundation whatever in the facts of the Hindu Science'.[44] In the siddhāntas one looks in vain for any connected account of the system,—history, names, member, orders etc. of the asterisms, presumably because this type of information is assumed on the part of the users of the text. Whitney pointed out another error in Biot's assumption, namely, that the declination circles passing through the junction stars cut up the ecliptic into a number of positions which, according to him, constituted the ancient system of lunar mansions. Such is not the case with the Sanskrit texts. By this method Biot transferred to Indian *nakṣatras* some of the characteristics of the Chinese *hsius* so as to strengthen his arguments in favour of his own opinions. In the Chinese system the declination circles through the *hsiu* stars divide the celestial sphere into a number of zones or mansions so that any planet crossing such a declination circle enters the corresponding *hsiu* mansion. In the Hindu astronomical *siddhāntas* the position of the junction star is defined with a view to facilitate the calculation of a conjunction; such definition does not mean the commencement of the planets' continuance in the *nakṣatra.* This *nakṣatra* is indeed a space, being one-twentyseventh part of the ecliptic of 360° or 800′ arc. The Moon spends about a day in each *nakṣatra* and momentarily comes into a state of conjunction with the junction star, generally the most conspicuous in the group of stars or constellations concerned. Whitney also gave a good exposition of the Hindu system of coordinates employed to represent the celestial objects in the sphere.

Weber assumed that the *nakṣatras,* like the *hsius,* are virtually single stars, marking out the heavens and giving names to the intervals. If that was really the case, Whitney commented, the Indian system must have undergone essential variations. The *Sūrya-siddhānta,* it is true, divided the ecliptic into 27 equal portions, but if these portions were carried from one group to the next one would arrive at quite a different series. Whitney pointed out that Garga and Brahmagupta had assigned one-twenty-seventh part of the ecliptic (800′ arc) equally to only 15 *nakṣatras,* the same amount

increased by half (1200′ arc) to each of 6 *nakṣatras,* and just half of the same (400′ arc) to each of the remaining 6 *nakṣatras.* On the question of 27 or 28 *nakṣatras,* the times of the *Taittirīya Saṃhitā* mentioning 27 and those of *Taittirīya Brāhmaṇa* and the *Atharvaveda* (19th book) mentioning 28 do not differ by such a great margin as to suggest the priority of either of them; possibly there was an intermingling of the two systems. Nevertheless Whitney conceded that upon Indian grounds alone the theory of the originality of the series of 27 *nakṣatras* expanding later on into one of 28, was more probable, although such a theory could not be forced by facts.[45]

Whitney arrived at the conclusion that the efforts of both Biot and Weber were of a negative character. If Biot's argument for the originality and immense antiquity of the *hsiu* system influencing countries lying farther west was entirely nugatory, Weber's attempt to prove the priority of the *nakṣatra* system leading to the *hsius* and the *manāzil* proved no less a failure. He was, therefore inclined to believe that probably some fourth people, different from all so far considered, were entitled to the honour of inventing the institution of lunar mansions, which in time diffused to other cultivated races of Asia.[46]

In the same volume of the *Journal of American Oriental Society,* Ebenezer Burgess, translator of the *Sūrya-siddhānta* traversed the same ground and expressed himself more or less in favour of the priority of the *nakṣatra* system. The system which he characterized as scientific was known in India as early as the fifteenth century B.C., and that, not as a semi-mythological fancy but as a scientific system based on astronomical observations and discoveries.[47] He agreed with Weber that the origin of 24 out of 28 *hsius* was of doubtful antiquity and that the full series of 28 did not appear in the Chinese literature earlier than 250 B.C. He pointed out that Biot's estimate of Chinese astronomy was based on exaggerated views of Romish missionaries, particularly those of Father Gaubil on which Delambre had already commented. After dealing in some detail with the coincidences and dissimilarities between the *hsius* and the *nakṣatras* he arrived at the conclusion that these two systems had no genetic relation to each other; if either was modified by the other, the modification was in this respect that the number 28 in the former was derived from the latter.[48]

Whitney had suggested the possiblity of a fourth nation outside the Indians, the Chinese and the Arabs, inventing the institution of lunar mansions. By his philogogical interpretation of 'mazzaloth', Weber was striving to show an old Babylonian connection with the Arabian *manāzil.* In 1891, Fritz Hommel, an assyriologist studied the Babylonian lunar stations, showed how their series of 24 lunar stations were derived from an original list of 36 normal stars, and concluded that these lunar and planetary stations made use of by the Babylonians at the time of the Arsacide kings could be the basis of the Arabic as well as of the Indian and Chinese series of stars and star groups delineating the ecliptic. Although he was primarily concerned with the origin and antiquity of the Arabian *manāzil,* his preference for old Babylonian as the home of invention of the most ancient system immediately attracted widespread attention. He even suggested that the lunar mansions originally numbered 24 and ultimately developed into the series of 27 or 28 farther East through

processes of diffusion. Hommel's Babylonian series with corresponding *manāzil* are given below :

Babylonian series	*Manāzil*
1. Timinnu, η Tauri	aṭ-ṭuriyā, η Tauri
2. Pidnu, α Tauri	al-debarān, α Tauri
3. Šur Narkabti, β, α, ζ Tauri	al-haq'a, λ, ϕ', ϕ Orionis
4. Pū Tu'āmi, η, μ Geminorum 5. Tu'āmi, Ša re'i γ Geminorum	al-han'a, η, μ, ν, γ, ξ Geminorum
6. Tu'āmi, α, β Geminorum	aḍ-ḍirā, α, β Geminorum
7. Pulukku, γ, δ, Cancri	an-naṭra, γ, δ Cancri
8. Ris arī, ϵ Leonis	aṭ-ṭarf, λ Leonis
9. Šarru, α Leonis	al-jabha, α Leonis
10. Māruša rību arkat, Šarri, ρ Leonis	az-zubra, δ, θ Leonis
11. Zibbat arī, β Leonis	aṣ-ṣarfa, β Leonis
12. Šipu arku ša ari, β Virginis 13. Šur ardati, γ Virginis	al-'awwā, β, η, γ Virginis
14. Nābu ardati, α Virginis	as-simāk, α Virginis al-ghafr, ι, κ, λ Virginis
15. Zibānītu, α, β Librae	az-zubānay, α, β Librae
16. Ris akrabi, δ, β Scorpionis	al-iklīl, δ, π, β Scorpionis
17. Ḫabrud, α Scorpionis	al-qalb, α Scorpionis
18. Mātu ša Kasil, θ Ophiuchi	as-Saula, λ, ν Scorpionis
19. Karan sug'ar, α, β Capricorni	ad-ḍābih α, β Capricorni Bula, ϵ, μ, ν Aquarii
20. Sug'ar, γ, δ Capricorni	as-su'ud, β, ξ Aquarii
21.	al-aḫbiya, α, $\bar{y}$, ζ , η Aquarii
22.	ad-dalwu, α, β, γ Pegasi; α Andromedae
23. Rikis nūni, η (Piscium)	al-ḥut, β Andromedae
24. Rīs Kuṣarikki, α, β Arietis	an-nath, β, γ Arietes al-buṭain, *a*, *b*, *c* Muscae

Hommel was aware that the Babylonian series of 30 or more stars differs obviously from the lunar zodiacs comprising 27 or 28 stars or star groups. He therefore argued that the Babylonian as well as Arabian and other series originally comprised 24 members only. As to the Arabian series he stated that (i) al-fargh al-awwal (α and β Pegasi) and al-farg aṣ-ṣāni (γ Pegasi and α Andromedae originally formed one mansion, (ii) aṣ-ṣarfah (β Leonis) was a later insertion, and Uttara and Pūrva phalgunī originally formed one *nakṣatra*, (iii) al-iklīl and as-zubānay was one station, and (iv) al-baldah was not possibly included in the original list.

George Thibaut, the noted indianist whose various contributions to Indian astronomy will be noticed presently found it difficult to accept Hommel's views.[49] From very early times the Babylonians had indeed a solar zodiac of twelve signs which could theoretically split into two or three parts giving rise to a series

of 24 or 36 stars but no proof existed that they actually used a series of 24 stations in connection with the lunar motion. The series of 27 or 28 was employed by the Indians, the Chinese and the Arabs to follow lunar motions, and represented divisions of the ecliptic. The Babylonian zodiac of 24 or more asterisms does not appear to be divided into an equal number of parts to which the motions of the Moon and planets are referred. For such reference they used the normal stars. When the members of the Babylonian series are compared with those of the three other systems disagreements are so wide as to militate against any diffusion theory. Whenever specially bright stars were selected for inclusion in the series agreements were inevitable; for example, α Tauri, α Leonis, α Virginis, and α Scorpionis are all stars of the first magnitude. Pleiades, α, β Geminorum, α, β Librae are well defined and conspicuous stars close to the ecliptic and could not fail to be included in any series intended to mark the ecliptic. The common origin theory with Babylon as the centre of diffusion was therefore no more successful than the efforts of the sinologists and the indianists to trace the origin of the lunar mansions to the *hsius* and the *nakṣatras* respectively.

Bhāu Dāji On Āryabhaṭa, Kern On Bṛhatsaṃhitā

In the sixties of the last century, while the lunar mansions controversy was in full swing, Bhāu Dāji examined the age and authenticity of Āryabhaṭa and other notable ancient astronomers.[50] He noticed two astronomical works,—*Mahā Ārya-siddhānta* and *Laghu Āryasiddhānta,* bearing the same name as their authors. The latter work was found to be the same as the *Āryabhaṭiya,* comprising the *Daśagitikā* and the *Āryāṣṭaśata* from which Brahmagupta and others quoted extensively and whose date was given by Colebrooke as the end of the fifth century A.D. Bhāu Dāji showed that this work was by Āryabhaṭa of Kusumapura (Paṭaliputra) who was born in A.D. 476 as clearly stated in the text. The other work was a much later compilation for which Bhāu Dāji fixed the date around A.D. 1322. In 1865 H. Kern produced a critical edition of Varāha's *Bṛhatsaṃhitā,* to which he added an illuminating preface contributing to our knowledge of ancient Indian astronomers and astrologers.[51] In connection with his study Kern collected all extracts from *Āryabhaṭiya* quoted by Bhaṭṭotpala in his commentary on the *Bṛhatsaṃhitā* and later on, following the discovery of the *Āryabhaṭiya* text, published the Sanskrit text with the commentary *Bhaṭadipikā* by Paramādiśvara from Leiden. It is needless to mention that the availability of the text greatly facilitated investigations into his mathematics and astronomy, much of which was carried out in the present century.

Vedāṅga Jyotiṣa

The *Vedāṅga Jyotiṣa* as an astronomical appendage to the Vedas had attracted attention from the early part of the nineteenth century. Weber in 1862 and Thibaut in 1877 presented a more or less full study of the text which only served to enhance the importance of an early notice of this subject by Colebrooke. In 1805, Colebrooke, in his pioneering studies of the Vedas or sacred writings of the Hindus, commented on the *Vedāṅga Jyotiṣa* as follows: "To each Veda, a treatise, under the title of *Jyotish,*

is annexed; which explains the adjustment of the calendar, for the purpose of fixing the proper periods for the performance of religious duties. It is adapted to the comparison of solar and lunar time with the vulgar or civil year; and was evidently formed in the infancy of astronomical knowledge. From the rules delivered in the treatises, which I have examined, it appears, the cycle (Yuga) there employed, is a period of five years only. The month is lunar; but at the end, and in the middle, of the quiquennial period, an intercalation is admitted by doubling one month."[52] Colebrooke also mentioned the *Jyotiṣa's* division of the zodiac into twenty-seven *nakṣatras* headed by Kṛttikā. Most importantly he noticed the placement of the colures in the *nakṣatra* circle in the important verse *svarākramete* etc. and gave a literal translation of the verse, which has been used in determining the antiquity of the astronomical knowledge embodied in the *Jyotiṣa.*

Weber, in his *Uber den Vedakalender Namens Jyotisham,* provided a complete and critical edition of the *Jyotiṣa* based on a number of manuscripts and a commentary by Somākara, together with a complete translation and explanation of the highly cryptic verses. He noted that, as an appendage of the Veda, like *śikṣā* and *chanda,* the *jyotiṣa* was available in two recensions, e.g. *Ṛk* containing 36 verses and *Yajus* with 43 or 45 verses. He noticed some Greek and Babylonian influence on the *Jyotiṣa,* particularly in its rules concerning the variation of day-lengths with seasons.[53]

Thibaut recognized the extremely corrupt form of all manuscripts containing Somākara's commentary due largely to the commentator's misunderstanding of the majority of the enigmatical rules. Somākara's chief merit consisted in his use of the *Gārgī Saṃhitā* and thereby preserving the quotations of the latter, no longer extant. The central feature of the *Jyotiṣa* is its adoption of a cycle of 5 years, beginning with the white half of the month of Māgha and ending with the dark half of the month of Pauṣa.[54] The year is obviously one-fifth of this cycle, and consists, according to verse 28, of three hundred and sixty-six days, six seasons, two *ayanas,* and twelve months considered as solar. The year meant is the tropical solar year. By comparing this with Garga's description of the quinquennial cycle, it is found that a *yuga* is composed of 1830 *sāvana* days, making the year consisting of 366 days. Weber supposed this tropical solar year to be an importation from a foreign country. Thibaut did not agree with him because both *yugas,* the Vedic as well as that of the *jyotiṣa* could not have been formed but for the knowledge of the difference of five years of 360 days and of 60 lunations from the time during which the Sun performed five tropical revolutions.

From the units of time measurement,—*kalā, nāḍikā, muhūrta, akṣara, kāṣṭhā* etc. Thibaut calculated a day to be equal to 603 *kalā,* a *tithi* 593 $\frac{17}{62}$ *kalā,* and a *nakṣatra* day 549 *kalā.* Somākara gave the duration of a *tithi* as 562 $\frac{4}{5}$ *kalā* manifestly much shorter than what it should be. Weber also noticed this discrepancy.

The *Jyotiṣa* recognized the variation of the day-length and gave a rule for finding the relative length of the day. The length of the nycthemeron is given as 30 *muhūrtas,*

that of the shortest day as 12 *muhūrtas* and that of the longest day as 18 *muhūrtas*. In the course of one *ayana* of 183 days the day-length increased by 6 *muhūrtas*, making the rate of increase per day 2/61 *muhūrtas*. From this rate the length of any day between the two solstices can be easily determined. Thibaut believed that such estimations of the longest and shortest days and the method of finding variations in day-lengths had generally prevailed in India before the impact of Greek science became obvious. The *Purāṇas*, the Jaina astronomical tracts like the *Sūryaprajñapti*, the *Paitāmaha-siddhānta* as summarized in Varāha's *Pañcasiddhāntikā* all give the same rule. One important point put forward in favour of borrowing is that variations of length of this order of magnitude are typical of latitudes in certain places of West Asia (e.g. Babylon), but it is also true of the extreme north-west corner of the sub-continent. "I am entirely of the opinion", observed Thibaut, "of Prof. Whitney who sees no sufficient reason for supposing the rule to be an imported one. It is true that the rule agrees with the facts only for the extreme north-west corner of India; but it is approximately true for a much greater part of India, and that an ancient rule—which the rule in question doubtless is, agrees best with the actual circumstances existing in the North-West of India is after all just what we should expect."[55]

The *Jyotiṣa* has dealt at considerable length with positions of the new and full moons in the *nakṣatras* during the whole quinquennial period. This question was of prime importance in Vedic times because of many sacrifices being performed on such days. In a five-year cycle there are 62 synodical *(cāndra)* months and therefore 124 *paryans*,—62 full moons and 62 new moons. On the basis of the Moon's passage in a synodical month of $29\frac{11}{62}$days and in a *pakṣa* of $14\frac{78}{124}$, Thibaut worked out the positions of all the 62 full and 62 new moons in the *yuga* in agreement with the text. In fact, the method represented another way of dividing the zodiac on the basis of 124 for readily reckoning the positions of new and full moons which served the purpose of a five-year calendar.

Jaina Astronomy

In 1865, Weber noticed a Jaina astronomical text, the *Sūryaprajñapti* and pointed out that it more or less embodied the same astronomical elements as characterized in the *Vedāṅga Jyotiṣa*.[56] Thibaut published a detailed study of the text in the *Journal of the Asiatic Society of Bengal* and showed that the system was based on a period containing 61 solar months of 30 *sāvana* days each, 62 lunar months and 67 sidereal revolutions of the Moon. These data yield 29.516129 days for the period of the Moon's synodic revolution and 27.313433 days for that of its sidereal. These periods are slightly shorter than those given in the *Sūrya-siddhānta*. In a period of 19 solar years there are 235 synodic months and 254 sidereal months of the Moon. If the corresponding number of days be worked out the Jaina text would give 14.084 days more than the *Sūrya-siddhānta* for 19 solar years, but 3.399 days and 2.093 days less than *Sūrya-siddhānta* values for the corresponding synodic and sidereal months. Thus the *Sūryaprajñapati*, like its Brāhmaṇa authority, the *Vedāṅga Jyotiṣa*, represents a less accurate system than the later *siddhāntas*.

Unlike the *Vedāṅga Jyotiṣa*, the *Sūryaprajñapti* uses a system of 28 *nakṣatras* of unequal space. Since a sidereal month consists of $819\frac{13}{20}$ *muhūrtas*, and on an average a *nakṣatra* accounts for a day, the Moon's passage through the asterisms must encompass 28 *nakṣatras*, one of them having a space of only $9\frac{18}{20}$ *muhūrtas*. But then the spaces are made unequal in such a way that one group of six (4th, 7th, 12th, 16th, 21st and 27th from *Aśvinī*) are assigned $1\frac{1}{2}$ days each, another group of six (2nd, 6th, 9th, 15th, 18th, and 25th) half a day each, and the rest 1 day each. Brahmagupta has given the value of the Moon's sidereal motion in degrees, minutes etc. as 13°10′34″..88, by adopting which Burgess has calculated the *nakṣatra* spaces as follows :—[57]

6 of 19°45′52″.32 each	—	111°35′13″.92
6 of 6°35′17″.44 each	—	39°31′44″.64
15 of 13°10′34″.88 each	—	197°38′43″.19
		355°45′41″.75
Abhijit for 0.3216673 day	—	4°14′18″.25
		360° 0 0

The balance space of 4°14′18″.25 is assigned to *Abhijit*.

The peculiarities of the Jaina astronomy demanded two sets of the Sun and Moon and *nakṣatra* series, for which Brahmagupta severely criticized the Arhats.

Varāhamihira's Pañcasiddhāntikā

Varāha's *Pañcasiddhāntikā* had been known, only in quotations and references from the early part of the nineteenth century. In 1874, G. Bühler in his search for Sanskrit manuscripts in the Bombay Presidency was rewarded with the discovery of two manuscripts of this important text. Ten years later Thibaut, in collaboration with Sudhakara Dvivedi, produced an edited text, a running translation of the cryptic verses, and an excellent introduction. Thibaut correctly assessed the importance of the work in Indian astronomical literature because of the author's predilection for historical approach. Varāhamihira, in Thibaut's judgement, was the only astronomer who realized the importance of various astronomical doctrines and systems current in his time even though some of them were defective, recorded a critical account of them, and did not hesitate to acknowledge the sources even when these were foreign. '*Pañcasiddhāntikā*,' he wrote, 'thus becomes an invaluable source for him who wishes to study Hindu astronomy from the only point of view which can claim the attention of the modern scholars, viz. the historical one.'[58]

Pañcasiddhāntikā is a *karaṇa* work in as much as it provides for a set of rules sufficient for speedy astronomical computations. It has mentioned a large number of *siddhāntas*, but selected only five most important among them, e.g. the *Sūrya-*,*Romaka-*,*Pauliśa*, *Paitāmaha*-and *Vaśiṣṭha-siddhānta* in order of importance. He considered the *Sūrya-*

siddhānta to be the most accurate, the next two, the *Romaka* and *Pauliśa* to be about equally correct, and the last two to be inaccurate. The five works extant in Varāha's time were not separately treated but often mixed up along with his own independent compositions. Thus in his introductory verses in ch.1 he deals with the method of computing *ahargaṇa* according to the *Romaka-siddhānta* along with an exposition of the principles of intercalation followed in the *Pauliśa-,Romaka-*, and *Sūrya-siddhānta.* Yet from the directions given at the end of the chapters Thibaut and Dvivedi had no difficulty in identifying Varāha's summary of the five *siddhāntas* as well as his own free discussions on the three fundamental questions *(tripraśna)*: the sphericity of the earth and the celestial sphere, instruments and observations, secrets of astronomy etc.

Starting with the least accurate of the five, the *Paitāmaha-siddhānta* is presented in ch. 12 in five stanzas. This *siddhānta* belongs to the category of the *Vedāṅga Jyotiṣa, Sūryaprajñapti* and *Garga Saṃhitā* and teaches a five-year luni-solar cycle comprising 5 solar years of 336 days, 60 solar, 62 synodical and 67 *nakṣatra* (sidereal revolutions of the Moon) months. The cycle commences at the moment of conjunction of the Sun and the Moon at the first point of Dhaniṣṭhā. Like the *Vedāṅga Jyotiṣa* the longest day is given as 18 *muhūrtas* and the shortest as 12 *muhūrtas*. There are some differences also. It gives a rule for calculating *Vyatipāta,* which is missing in the *Jyotiṣa* and the *Prajñapti.*

Some of the elements of the *Vaśiṣṭha-siddhānta* are discussed in chapters 2 and 18 (last chapter according to Thibaut). That the 2nd chapter embodied Vaśiṣṭha's teachings was attested by Varāha in the last stanza 13 'this is the calculation of the shadow according to the concise *Vaśiṣṭha-siddhānta*'. This chapter deals with, among other things, rules for calculating the length of the day at any time of the year, but these rules, although reminiscent of those given in the *Paitāmaha-siddhānta* and the *Vedāṅga Jyotiṣa,* give different values for the shortest and longest days. The chapter also provides rules for finding the length of the shadow, the mean longitude of the Sun and the *lagna,* which, notwithstanding their primitive nature, are superior to what *Paitāmaha* supplies. Thibaut also noted that Vaśiṣṭha operated with a sphere divided into signs, degrees and minutes in place of the ancient stellar zodiac.

Assuming that the small second chapter contained all that Vaśiṣṭha had to say, Thibaut was inclined to think that certain parts of the work were probably missing. Nevertheless he suspected, but did not definitely say, that the last chapter dealing with the courses of the planets probably contained some of the elements of Vaśiṣṭha's teachings. The rules give methods of computing the number of heliacal risings of planets in a given *ahargaṇa.* From the synodical revolutions thus found are determined the sidereal motions of the planets. Although he found many of the rules obscure and unsatisfactory, he recognized in them elements which did not differ greatly from those generally employed in Hindu astronomy.[59] The chapter itself does not provide any indication as to the sources from which the rules were compiled, but on the basis of the statement *vaśiṣṭha siddhānte śukraḥ,* he commented, "If we accept the former statement as true, it would follow that the *Vaśiṣṭha-siddhānta* possessed an accurate knowledge of the length of the planetary revolutions; for although the statement

directly refers to Venus only, it is—for reasons not requiring to be set forth at length—altogether improbable that the *Vaśiṣṭha-siddhānta,* or in fact any *siddhānta,* should have been well informed about the theory of one planet only."[60]

On the question of the relationship of Varāha's *Vaśiṣṭha-siddhānta* and another work bearing the same name and known from the quotations of later authors, Thibaut particularly referred to Brahmagupta's quotation and suggested Viṣṇucandra as the author of the latter. Viṣṇucandra probably had access to the original *Vaśiṣṭha-siddhānta,* used its elements, and distorted the original teachings through a faulty understanding. The same Brahmagupta further informs us that one Vijayanandin was associated with the compilation of a *Vaśiṣṭha-siddhānta* and this Vijayanandin's name is further mentioned by Varāha himself in the last chapter in connection with planetary motions. None of the *Vaśiṣṭha-* versions compiled by Viṣṇucandra and Vijayanandin has survived. One *Laghu Vaśiṣṭha-siddhānta* (edited by Vindhyesvari Prasad Dube in 1881) which Thibaut examined did not agree with the teachings of the version summarized by Varāha, so that the question of authorship of the original *Vaśiṣṭha-siddhānta* remained an open one.

Astronomical elements of the *Romaka-siddhānta* are scattered over chapters 1, 4, 8. The *Romaka* used a *yuga* of 2850 years, containing 1050 intercalary months *(adhimāsas)* and 16547 omitted lunar days *(tithipralayas)*. Reduced by 150 these elements lead to the well known metonic cycle of 19 solar years containing 235 synodical months and 7 intercalary months. Thibaut also deduced the number of natural or civil days in this *yuga* and determined the year length to be 365^d5^h 55′12″, agreeing with the tropical year of Hipparchus of Ptolemy. The rules for computing the *ahargaṇa* for finding the mean longitudes of planets are given in ch. 1 and the mean longitudes of the Sun and the Moon in ch. 8. The Moon's sidereal revolution is stated to be $27^d7^h43'6.3''$. The Moon's anomalistic month is worked out to be $27^d13^h18'32.7''$ from the revolution of its *kendra* 110 times in 3031 days. For the correction of the Sun's mean motion, the longitude of its apogee is given as 75°. Although no general rule for finding the equation of the centre is provided its values for anomalies 15°, 30°, 45°, 60°, 75° and 90° are given, some of which agree closely with those of Ptolemy, as shown below :

Degree of Anomaly	15	30	45	60	75	90
Equation of Centre: Romaka	34′42″	1°8′37″	1°38′39″	2°2′49″	2°17′5″	2°23′23″
Equation of Centre: Ptolemy		1°9′		2°1′		2°23′

The Moon's equations are likewise dealt with, but the values given disagree with those by Ptolemy. The period of the revolution of the Moon's node is given as 6796 days 7 hours closely agreeing with Ptolemy's value of 3796^d 14^h etc. Other elements presented include the angular diameters of the Sun and the Moon as 30′ and 34′ respectively, the parallax in longitude of the Sun and the Moon (the difference is given), and the parallax in latitude of the Moon, that of the Sun being neglected. Another peculiarity of the *Romaka* is that the meridian of Yavanapura is adopted for *ahargaṇa* computation and that of Ujjayinī, for determining the mean places of the Sun, Moon and other planets.

Colebrooke and Bhāu Dāji, on the authority of Brahmagupta and his commentator Pṛthūdakasvāmī attributed to Śrīṣeṇa the authorship of the original *Romaka-siddhānta*. By comparing a number of manuscripts of the *Brāhmasphuṭasiddhānta.* (Bombay Government, Benares College and Royal Library of Berlin) Thibaut established that the manuscript used by Colebrooke was defective, and that Śrīṣeṇa was not an original writer but a careless compiler from various authorities. Thus he borrowed from Lāṭa rules concerning the mean motions of the Sun and Moon, and Moon's apogee and node, and the mean motions of Mercury's *śighra,* Jupiter, Venus' *śighra* and Saturn, and from Āryabhaṭa those relating to apogees, epicycles and nodes, and also the true motions of planets. As regards the *Romaka,* Śrīṣeṇa borrowed several elements from various heterogeneous sources and incorporated them in the original *Romaka-siddhānta,* and thereby transformed 'a heap of jewels' into 'a patched rag' *(śrīṣeṇena gṛhītvā ratnoccayo romaka kṛta kanthā).*[61] Thus, there was an original *Romaka-siddhānta* in many ways different from the revised and inferior text due to Śrīṣeṇa, on the authority of Brahmagupta. If Śrīṣeṇa be out, what would be the position of Lāṭadeva in connection with the *Romaka-siddhānta*? In ch.I, 3, Varāha himself mentioned Lāṭadeva as an expounder of the *Romaka-siddhānta* and also as an able astronomer who directed the computation of *ahargaṇa* from the moment the Sun had half set at Yavanapura. From this as also from Brahmagupta's references to Lāṭa, Thibaut rated him as an astronomer of no mean order, who in all probability did not write an ordinary commentary of the *Romaka,* but carried out the more difficult task of recasting the original so as to conform to a later epoch, namely Śaka 427, which Varāha adopted for his *Pañcasiddhāntikā* with Lāṭa's version of *Romaka* before him.

The elements of the *Pauliśa-siddhānta,* according to Thibaut, are discussed in chapters 1, 2, 3, 4, 5 and 6. The *ahargaṇa* rules given in ch.1 are marked by the distinction that the computations are not based on any cyclic period comprising integral numbers of years, lunar months and omitted lunar days, but are carried out directly by setting up a small aggregates of days containing approximately one intercalary month or one omitted lunar day. The rules for finding lunar positions, as discussed in ch.2, proved even more intriguing. Thibaut succeeded in interpreting these rules by applying the *Vākyam* process as obtaining among astronomers in South India and explained long ago by Bailly and John Warren. The merit of this process is that true places of the Sun and the Moon can be found without first obtaining their

mean places. For this purpose four periods called *Vedam, Rasa Gherica, Calanilam,* and *Devaram* and consisting of 1600984, 12372, 3031 and 248 days respectively are used. These periods are such that the Moon can undergo complete anomalistic revolutions, e.g. *Devaram*—9 revolutions; *Calanilam*—110 revolutions; etc. For the motion of the Sun, however, the procedure appears to be based on the determination of the mean positions and applying to them the equation of centre of which a few values are given. Although no formula for finding the equation of centre is given, eccentric (or epicyclic)-cum-trigonometrical methods are indicated behind these values. The longitude of the Sun's apogee is stated to be 80°. Convenient numerical formulas for the computation of the eclipses are given, but no exposition of the theory of eclipse. Chapter 4 gives a sine table for $R=120'$, but it cannot be ascertained whether it is typical of the *Pauliśa-siddhānta* or a general table applicable for computations in accordance with the elements of the three *siddhāntas, Romaka, Pauliśa* and *Sūrya.*

Varāha's scholiast Bhaṭṭotpala and Brahmagupta's Pṛthūdakasvāmī have frequently quoted from an astronomical work bearing the same name as the *Pauliśa-siddhānta.* From the investigations of these quotations by Colebrooke it was already known that the later *Pauliśa-siddhānta* used the elements of Āryabhaṭa, the *Sūrya-siddhānta,* and later authorities had already assumed the characteristics of later *siddhānta* texts. Thibaut noted important differences between Varāha's *Pauliśa* and that of the commentators,—in the length of the year, *ahargaṇa* computations, determination of planetary places and other features, which clearly indicate that the original work underwent a number of recasts.[62]

The *Sūrya-siddhānta,* the most accurate of the five systems according to Varāha's judgement has naturally claimed the largest space, its elements being spread over chapters, 1, 9 (solar eclipses), 10 (lunar eclipses), 11 (projection of eclipses), 16 (mean motion and planets) and 17 (true motion of planets). The importance of Varāha's account of the text as known to him is obvious in as much as this is the only astronomical system to have survived to the modern times. For purposes of comparison Thibaut chose to call Varāha's account as the old *Sūrya-siddhānta* and the text that has come down to us as the modern *Sūrya-siddhānta.* The old SS. uses as its period one-twentyfourth of a *mahāyuga* of 4,320,000 years, that is, 180,000 years and gives the number of intercalary months and omitted lunar days as 66389 and 1045095, from which the number of *sāvana* days in a *mahāyuga* works out to 1577917800; in the modern SS. this number is in excess by 28 days. This difference is reflected in the length of the year, the old SS. making it as $365^d\ 6^h\ 12'\ 36''$ as against the modern SS's value of $365^d\ 6^h\ 12'\ 36.''56$.

As to the elements of the Moon, its sidereal revolutions in the *mahāyuga* have the same value in both, slightly affecting the length of the period. Some other elements are tabulated below ;

	Old SS	Modern SS
Period of revl. of Moon's apogee	$3231^d\ 23^h\ 42'16.76''$	$3232^d\ 2^h\ 14'53.4''$
Revls. of Moon's apogee in a *mahāyuga*	488,219	488,203
Revls. of Moon's node in a *mahāyuga*	232,226	232,228
Moon's greatest latitude	270′	270′

Thibaut noted that the figures of the revolutions of the Moon's apogee and node and of its greatest latitude as given in the old SS. agreed with those given by Āryabhaṭa. In the computation of the Sun's equation of centre the longitude of its apogee is an important parameter; the old SS. gives it as 80° while the modern SS. and the *Āryabhaṭiya* advise the use of 77° and 78° respectively. The old SS. does not mention any motion of the Sun's apogee; but the modern *siddhāntas* recognize such a motion albeit very slow.

For planetary revolutions Thibaut compared the values given in the two *siddhāntas,* to which we add Āryabhaṭa's values as given in his *Ārdharātrika* system:

	Old *SS.*	Modern *SS.*	Āryabhaṭa *(Ārdharātrika)*
Mercury	17,937,000	17,937,060	17,937,000
Venus	7,022,388	7,022,376	7,022,388
Mars	2,296,824	2,296,832	2,296,824
Jupiter	364,220	364,220	364,220
Saturn	146,564	146,568	146,564

While the two *Sūrya-siddhāntas* disagree in all the cases except Jupiter, the old *SS.* agrees with Āryabhaṭa and also with Pauliśa as quoted by Bhaṭṭotpala. Regarding planetary apogees and dimensions of *manda* and *śighra* epicycles, Thibaut reported agreement between the old SS. and Brahmagupta's *Khaṇḍakhādyaka* but not so in respect of the modern SS. and the *Āryabhaṭiya.* The formulae by which the two inequalities are directed to be calculated are the same in the two *siddhāntas.*

Thibaut made it clear that a correct understanding of the evolution of the five *siddhāntas* would be necessary to form a fairly accurate notion of the transition of Indian astronomy from the pre-scientific stage to its modern form. The *Paitāmaha-siddhānta,* clearly based on the *Vedāṅga Jyotiṣa, Garga Saṃhitā,* and the Jaina astronomical concepts, represented the pre-scientific stage. The *Vaśiṣṭha-siddhānta,* representing a more advanced form, probably belonged to the transitional period. The remaining three siddhāntas,—*Romaka, Pauliśa* and *Sūrya,* represented the modern phase of Hindu astronomy and were inspired by Greek teaching.[63] Thibaut thought it highly probable that the earliest Sanskrit works in which this inspiration manifested ttself were the *Pauliśa* and the *Romaka,* using the Metonic cycle, the tropical year, giving the longitude difference between Ujjayinī and Yavanapura, and computing *ahargaṇas*

from the meridian of the latter. But all sorts of difficulties arise when we attempt to pinpoint the channels of transmission. The great influence and prestige of Ptolemy in the ancient world would have suggested his *Syntaxis* as the source of main inspiration in Indian astronomical renaissance, but such a conjecture is negatived by a comparison of any of the early *siddhāntas* of this transitional period with the Greek astronomical masterpiece. Whitney had suggested that the original transmission took place before Ptolemy, possibly between the time of Hipparchus and Ptolemy. Thibaut considered the possibility of the *siddhantās* deriving the Greek elements from manuals, astrological works and tracts concerning calendar making, a class of literature quite different from scientific astronomical treatises worked up by men like Hipparchus, Ptolemy or Theon. Such a conjecture, he believed, would 'help to render the whole process of transmission more intelligible.'[64] In recent years some good results have actually been achieved through investigations of the Greek and Sanskrit astrological literature of this period.

AL-BĪRŪNĪ ON INDIAN ASTRONOMY

In the seventies of the last century Edward C. Sachau, of the Royal University of Berlin edited and translated into German and English al-Bīrūnī's *Kitāb Taḥqiq mā li 'l-Hind.* The manuscript of the Arabic text was prepared in 1872, a German translation of it between 1883 and 1884, and an English translation during 1885-86. The Arabic text appeared in print in 1885-86 and the English translation two years later in 1888. The work brought to light the investigations into astronomy and other sciences of India as well as into the history, geography, literature, manners, customs and beliefs of the peoples of the sub-continent by one of the greatest of scholars and scientists produced in the Arab culture area in the medieval times. Al-Bīrūnī's scientific interests were of an encyclopaedic nature extending from astronomy, mathematics and geography to medicine, religion, philosophy and magic. As an orientalist in his endeavours to understand the contributions of the Indians in exact sciences from original sources he achieved in the beginning of the eleventh century under adverse circumstances what European orientalists with much better equipments and facilities struggled to do in the beginning of the nineteenth century. Reinaud's *Memoire geographique historique et scientifique sur l'Inde* (Paris, 1849), Steins Chneider's papers on the history of translations from Sanskrit into Arabic and their influence on Arabic literature in the *ZDMG,* Fluggel's translation of *Fihrist,* Gildemeister's *Scriptorum* and a few other works had provided some glimpses into Indo-Arabic scientific exchanges at the beginning of the Arab intellectual revival. Sachau's translation and elaborate notes provided new materials for a better understanding of the state of scientific and astronomical knowledge of the Indians before al-Bīrūnī's time.

In the foundation of Arabic literature laid between A.D. 750 and 850, Sachau observed, the literature of Greece, Persia and India were taxed to help remove the sterility of the Arab mind.[65] As far as India's contribution is concerned, it reached Bagdad in two different roads as also in two different periods. Some of the Sanskrit works were directly translated into Arabic and others travelled through Iran having

been first translated from Sanskrit or Pali into Persian and subsequently from Persian to Arabic. The first period was during the reign of Khalif al-Manṣūr (A.D. 753-774) and the second in Harun al-Rashid's time (A.D. 786-808). In the first period when Sindh was under the Khalif's rule, Indian embassies visited Bagdad, and such opportunities were probably utilized for the exchange of scholars. It was in this way that the Arab scholars came in contact with Indian astronomers and first learnt of Brahmagupta's two astronomical texts *Brahmasiddhānta (Sindhind)* and *Khaṇḍakhādyaka (Arkand)*. These two works were translated by al-Fazārī and by Ya'qub ibn Ṭāriq with the help of Indian pandits and were possibly the first works to introduce the Arab scholars into a scientific system of astronomy.[66] Muḥammad ibn Ibrahim al-Fazārī hailed from a family of scientists and technicians, his father being a reputed astrolabe-maker and was the first propagator of Indian astronomy among the Arab scholars. Al-Bīrūnī quoted from his work, informed us of his use of the word *pala* meaning a 'day-minute' and his method of computing the longitude of a place from two latitudes, and discussed his planetary cycles as derived from Indian astronomers. "These star-cycles as known through the canon of Alfazārī and Ya'qūb Ibn Ṭāriq," al-Bīrūnī wrote in his *India*, "were derived from a Hindu who came to Bagdad as a member of the political mission which Sindh sent to the Khalif Almanṣūr, A.H. 154 (=A.D. 771). If we compare these secondary statements with the primary statements of the Hindus, we discover discrepancies, the cause of which is not known to me."[67]

Ya'qūb Ibn Ṭāriq, frequently mentioned by Bīrūnī, was well versed in astronomy, chronology and mathematical geography as practised in India. Al-Bīrūnī quoted his measures of the circumference and the diameter of the zodiacal sphere in *yojanas*, which agreed with the system of Pauliśa; the radius and circumference of the earth; and discussed his method for the computation of solar days in the *ahargaṇa*, which he found as incorrect. Bīrūnī remarked, "We have already pointed out..a mistake of Ya'qub Ibn Ṭāriq in the calculation of the universal solar and *ūnarātra* days. As he translated from the Indian language a calculation the reasons of which he did not understand, it would have been his duty to examine it, and to check the various numbers of it one by the other. He mentions in his book also the method of *ahargaṇa*, i.e. the resolution of years, but his description is not correct..."[68] In his account of the order of planets, their distances and sizes (ch. LV), Bīrūnī fully utilized the data given by Ya'qūb because 'the only Hindu traditions we have regarding the distances of the stars are those mentioned by Ya'qūb Ibn Ṭāriq in his book, *The Composition of the Spheres*, and he had drawn his information from the well-known Hindu scholar who in A.H. 161, accompanied an embassy to Bagdad."[69]

In discussing the important methods, processes and doctrines, Bīrūnī did not proceed on the basis of a single standard text, but gathered his materials from a number of *siddhāntas*, *tantras* and *karaṇas*. Under *siddhāntas* he included those works which were straight and not crooked or changing. *Tantras* or *karaṇas* represented another class of astronomical literature, which operated upon or followed a *siddhānta*. He thought that the Hindus had five *siddhāntas*, e.g. the *Sūrya-siddhānta* composed by Lāṭa, the *Vasiṣṭha-siddhānta* by Viṣṇucandra, the *Puliśa-siddhānta* by

one Puliśa, the Greek from the city of Alexandria (Saintra), the *Romaka-siddhānta* composed by Śriṣeṇa, and the *Brahmasiddhānta* by Brahmagupta, son of Jiṣṇu from Bhillamala between Multan and Anhilwara. He also mentioned Varāhamihira's *Pañcasiddhāntikā* as an astronomical handbook of small compass, but probably he did not get a copy of it as it appears from his statement: 'the name does not indicate anything but the fact that the number of *siddhāntas* is five."[70] Of these five *siddhāntas* he was able to procure the books of Puliśa and Brahmagupta from which he quoted extensively. As an example of *tantra* he mentioned the work of Āryabhaṭa and Balabhadra. Under *karaṇa,* he included Brahmagupta's, *Khaṇḍakhādyaka* representing the doctrine of Āryabhaṭa, Vijayanandin's *Karaṇa-tilaka,* Vitteśvara's *Karaṇa-sāra,* Bhānuyaśa's *Karaṇa-para-tilaka* and a number of *karaṇa* works by Utpalas. Āryabhaṭa's *Daśagitikā* and *Āryāṣṭaśata* were also mentioned under this class. Moreover, several astrological *saṃhitās,* and *jātakas* or books of nativities are mentioned as his sources. Another important aspect of Bīrūnī's researches was his intensive use of the astronomical information contained in the *Purāṇas,* of which his main sources were *Vāyu, Viṣṇu, Matsya* and *Āditya Purāṇas.*

Bīrūnī did not follow the usual chapter sequence typical of astronomical texts in arranging his topics. He introduced a large number of small chapters to discuss one astronomical topic or concept at a time such as planetary names, zodiacal signs and lunar stations (ch. XIX): shape of heaven and earth (XXVI): Laṅkā, the coupola of the earth (prime meridian) (XXV): geographical longitudes (XXXI): various kinds of day (XXXIII): four measures of time *(sāvana-māna, cāndra-māna, nakṣatra-māna, tithi)* (XXXVI): definition of *kalpa* and *caturyuga* (XLI): starcycles in a *kalpa* and *caturyuga* (L): *adhimāsa, ūnarātra, ahargaṇa* (LI): calculation of *ahargaṇa* (LII, LIII): computation of mean longitudes of planets (LIV): order of planets, their distances and sizes (LV): lunar stations (LVI): solar and lunar eclipses (LIX): *parvan* (LX): Jupiter's sixty-year cycle (LXII). The list is not exhaustive. For each subject he presented the views of different authorities, critically examined them, and gave his own verdict in a true scientific spirit.

The Age of the Vedas from Astronomical Considerations

In the closing years of the last century H. Jacobi and B. G. Tilak interpreted certain passages of the *Ṛgveda* and the *Brāhmaṇas* as indicating the positions of the solstices and equinoxes in the stellar zodiac and suggesting from the known rate of precession the date of these texts. Jacobi's explanation of the 'frog hymn' in the *Ṛgveda,* VII, 103, 9, placing this *Saṃhitā* in the fifth millennium B.C. originally appeared in the *Festschrift* on the occasion of Prof. Roth's jubilee, translated into English By J. Morison for the *Indian Antiquary* (23, 154-159, June 1894). Tilak's paper entitled 'Orion' was presented at the Ninth International Oriental Congress, an abstract of which was published in the volume of the Congress. Bühler put on record that the honour of having found the new method of utilizing astronomical facts, mentioned in Vedic literature, belonged to Jacobi and Tilak jointly, though the latter had published his results earlier.[71]

The 'frog hymn' runs as follows: "They observe the sacred order of the year, they never forget the proper time, those men, as soon as in the year the rain time has come, the hot glow of the sun finds its end." Jacobi interpreted this hymn as indicating the beginning of the year with the rainy season on the basis of which terms '*varṣa*' or '*abda*' (rain-giving) were coined for the year.[72] From the *Sūryasūkta,* X. 85, 13 and its variant in the *Atharvaveda,* XIV, 1, 13, Jacobi further suggested that the summar solstice from which the early Ṛgvedic year began was then in Phalgunī. When the Sun at the summer solstice was in Phalgunī, the full-moon was in Bhadrapadā or Prauṣṭhapadā thus coinciding with the onset of the rainy season (Fig. 3.3). In this scheme the positions of the autumnal and vernal equinoxes would clearly be at the *nakṣatras* Mūla and Mṛgaśiras. At the autumnal equinox in Mūla

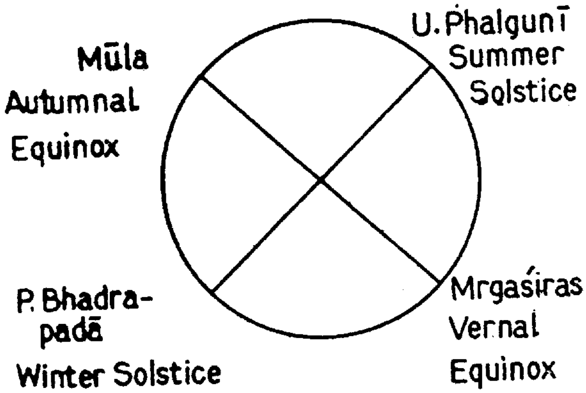


Fig. 3.3

the corresponding month from the full-moon in Mṛgaśiras was *Agrahāyaṇa,* which was the first month of the *śarad* year reckoned from the autumnal equinox. Moreover, Mūla was probably the first *nakṣatra* at one time which agrees with its etymological meaning "root-beginning". Its other name *vicṛtau* meaning 'dividers' points in the same direction. No less significant is the meaning of the preceding *nakṣatra* as Jyeṣṭha meaning the 'oldest', that is to say, the *nakṣatra* that kills or closes the old year.[73] Jacobi also suggested another year, the *himā* year, starting with the winter solstice in the month of *Phālguna,* because this month has often been described as the mouth (*mukhaṃ vā etat saṃvatsarasya yat phalgunī pūrṇamāsāt, Pañc. Br.* 5, 9.9).

Jacobi gave a table of longitudes of the principal stars of the *nakṣatras* for the years A.D. 560, 0 B.C., 1000 B.C., 2000 B.C., 3000 B.C., and 4000 B.C. In 4000 B.C. the longitudes of stars marking the equinoxes and the solstices were as follows: Mṛgaśiras—5°38; U. Phalgunī—93°.32; Mūla—186°.26; and P. Bhadrapadā—275°. 16. Therefore such a Vedic year and year beginning appear to have obtained a few centuries earlier than this date.

Tilak proceeded in a different way. In the *Vedāṅga Jyotiṣa* the year was no doubt made to commence with the winter solstice. The various sacrifices like the *gavām*

ayana also commenced from the winter solstice day. This also appears to be the case from the use of the term *uttarāyaṇa* which meant the phenomenon of the Sun's turning north at the winter solstice. Here Tilak pointed out that in an earlier time this was not the case. The middle day of the annual *satra* is called the *viṣūvān* day, and this *viṣūvān* is the equinoctial day when the day and night are equal in length. Tilak then draws attention to the words '*devayāna*' and '*pitṛyāna*' frequently occurring in the *Saṃhitās, Brāhmaṇas* and *Upaniṣads*. These two paths, according to Tilak, represent the two halves of the ecliptic, *devayāna* representing the *uttarāyana* with which the three *deva* seasons, e.g. spring, summer and rains are associated, and *pitṛyāna* answering for the other half connected with the three *pitṛ* seasons *śarad, hemanta* and *śiśira*. The commencement of the former was thus marked by the vernal equinox and that of the latter by the autumnal one. "We must, therefore, hold," observed Tilak, "that *devayāna* in those days was understood to extend over the six months of the year, which comprised the three seasons of spring, summer and rains, i.e. from the vernal to the autumnal equinox, when the Sun was in the northern hemisphere or to the north of the equator."[74]

Having established that there were at least two year beginnings in the Vedic times, one at the vernal equinox and the other at the winter solstice, Tilak examined the question of the correlation of the *nakṣatra* series with the vernal equinox. He showed that in the *Vedāṅga Jyotiṣa* the vernal equinox was placed in the last quarter of Bharaṇī, from which a natural conclusion would follow that the vernal equinox coincided with Kṛttikā at the time of the *Taittirīya Saṃhitā*. Moreover, different statements of the *Taittirīya Saṃhitā* and *Brāhmaṇa* pointed to the same conclusion: "*firstly,* the lists of the *nakṣatras* and their presiding deities, given in the *Taittirīya Saṃhitā* and *Brāhmaṇa* all beginning with Kṛttikās; *secondly,* an express statement in the *Taittirīya Brāhmaṇa,* that the Kṛttikās are the mouth of the *nakṣatras; thirdly,* a statement that the Kṛttikās are the first of the *Deva Nakṣatras,* that is, as I have shown before, the *nakṣatras* in the northern hemisphere above the vernal equinox; and *fourthly,* the passage in the *Taittirīya Saṃhitā* above discussed, which expressly states that the winter solstice fell in the month of *Māgha*. The vernal equinox is referred to the Kṛttikās directly or indirectly in all these passages.."[75] On this basis, the date of the *Taittirīya Saṃhitā,* as shown by Whitney in his notes to the translation of the *Sūrya-siddhānta,* worked out to be 2350 B.C. If the placement of the corresponding asterism be taken to be 10°51′ from the initial point in the zodiacal circle, the date would be reduced by 792 years, or to about 1426 B.C.

Tilak then proceeded to prove the existence of another hidden internal evidence in the Vedic literature which pointed to a still remoter antiquity. This evidence is connected with certain passages in the *Taittirīya Saṃhitā* stating that the Citrā and Phalgunī full-moons *(citrā-pūrṇa-māsa* and *phalgunī-pūrṇa-māsa)* were the beginnings of the year. He argued that the year beginning with the full-moon in Phālguna meant the coincidence of the winter solstice with the asterism Uttara Bhadrapadā, the summer solstice in Uttara Phalgunī, the vernal equinox with Mṛgaśiras and the autumnal equinox with Mūla, In other words, Tilak arrived at the same positions of the equinoxes and colours *vis-à-vis* the *nakṣatra* (Fig. 3·3) as did Jacobi from his consi-

deration of the 'frog-hymn'. In analogy with the Kṛttikā, the Mṛgaśiras was then the mouth of the *nakṣatras*. Although no textual support in favour of this could be provided, the corresponding month of *Agrahāyaṇa*, also known as Mārgaśīrṣa was then possibly the first month of the year inasmuch as *āgrahāyaṇi* literally means 'commencing the year'.[76] Significantly enough the asterism Mūla was then 180° further from Mṛgaśiras. "I should rather suggest," continued Tilak, "that Mūla was so called because its acronycal rising marked the commencement of the year at the time when the vernal equinox was near Mṛgaśiras and winter solstice fell on the Phālgunī full-moon."[77] This is the same scheme as was hit upon independently by Jacobi, pointing to the antiquity of the Vedic literature in the neighbourhood of 4000 B.C.

Bühler welcomed these contributions as providing evidence for year-beginnings on various dates in the Vedic times. If the high antiquity of the Vedic literature following from astronomical considerations were somewhat hard to accept, Jacobi and Tilak's work provided support to the findings of research workers in the field of Brahmanical, Buddhist, and Jaina literature that the Indo-Aryan history extented very considerably beyond 1500 B.C.[78]

Whitney completely disagreed with the views expressed in these two papers. The authors, in his view, brought forward nothing that could force to change the hitherto current views on the antiquity of the sacred literature of the Indians. All inferences drawn from the *Brāhmaṇas* regarding year beginnings appeared to him 'helplessly weak support for any important theory.' As to Tilak's *devayāna* and *pitṛyāna* there was nothing so far brought to light in the *Ṛgveda* that would admit of *ayanas*, equinoxes and solstices being regarded as distances and points. That *agrahāyaṇa* itself designated the asterism Mṛgaśiras and proved to have been the first asterism of a series beginning and ending with the year was, according to Whitney, by no means to be credited in the absence of any passage exhibiting such use.[79]

Thibaut also disagreed with the views of Jacobi and Tilak, but before doing so he analyzed the same passages of the *Taittirīya Saṃhitā* and *Tāṇḍa Brāhmaṇa* with a view to proving that these admitted of a different interpretation. In the process he gave a masterly analysis of the Vedic months, years, solstices, *gavām ayana* and other relevant sacrificial rites which throw some light on the knowledge of astronomy in the Vedic times. About the Kṛttikā and Mṛgaśiras series simultaneously leaving their traces in the same Vedic texts, from which their two different degrees of antiquities separated by about 2000 years could be inferred, Thibaut observed, "It is certainly not antecedently probable that the Brāhmaṇa texts exhibited by us should, within their short compass, contain records of observations separated from each other by several thousands of years."[80] His other objections may be summarized as follows: (1) The month *Phālguna* as the mouth of the year occurs in several places of the *Brāhmaṇas* and has no more significance than a mere opinion: (2) solstices in Vedic India were looked upon as marking the beginning of the year: (3) in the Brāhmaṇa period full-moon in Phalgunī could not have coincided with the vernal equinox; (4) in India, vernal equinox did not in any way mark an important point in the

revolution of the seasons; accordingly, equinoxes or anything connected with them are nowhere in the Vedic literature referred to either directly or indirectly; (5) the beginning of the spring of the *Brāhmaṇas* is thus in no way connected with the vernal equinox.

Thus by the end of the nineteenth century the study of ancient Indian astronomy was placed on a firm footing through the discovery of several important manuscripts and publication of their critical editions and translations. Most of the important authors and their commentators of the classical and medieval periods were reviewed and brought to light. The extent and quality of pre-scientific astronomical knowledge during Vedic times became crystallized. The study of Varāha's *Pañcasiddhāntikā* threw a flood of light on the transition of Indian astronomy from the pre-scientific to the scientific stage. Reinaud's notices and Sachau's translations of Al-Bīrūnī's investigations revealed the reception of Indian astronomy in the Arab countries during the early medieval period. Thus, was laid a solid and broad foundation for the history of astronomy in India from which to attempt further refinements and more detailed studies in the new century opened up. An admirable summary of the progress of knowledge in ancient India's contribution to astronomy, astrology and mathematics was given by Thibaut in the *Grundriss* in 1899.[81]

PROGRESS IN THE TWENTIETH CENTURY

Vedic Knowledge of Planets

Weber did not notice the mention of planets in any texts earlier than the *Taittirīya Āraṇyaka.* This raised the question whether the Vedic Hindus were acquainted with the planets. The seven *ādityas* mentioned in the *Ṛgveda* (IX. 114. 3) were interpreted by Oldenberg as referring to five planets in addition to the Sun and the Moon. Ludwig likewise interpreted the number 34 mentioned in the *Ṛgveda* (X. 55-4; I. 162.18) as the sum of 27 *nakṣatras,* 5 planets and the Sun and the Moon. In the *Orion,* Tilak showed that the words *śukra, manthin* and *vena* were sometimes mentioned in the *Ṛgveda* and the *Brāhmaṇas.* In his paper on Bṛhaspati and Tiṣya, Fleet quoted passages from the *Ṛgveda* and the *Taittirīya Brāhmaṇa* to prove that Bṛhaspati mentioned in them clearly referred to planet Jupiter. Thus, he gave *Ṛgveda,* 4.50.4 in English translation as follows: "Bṛhaspati, when first being born from a great light or brightness in the highest heaven, seven mouthed, of a powerful nature, seven rayed, with a deep sound blew away the darkness."[82] In the *Taittirīya Bṛāhmaṇa* (3.1.1.5.), Bṛhaspati is mentioned in connection with the *nakṣatra* Tiṣya in an astronomical sense, as follows: "Bṛhaspati, when first being born, came into existence over against the *nakṣatra* Tiṣya—he the best of the gods, victorious against hostile armies: let us be free from fear in all directions." These two verses are clearly related. Bṛhaspati again is the regent or presiding deity of the *nakṣatra* Tiṣya or Puṣya. This *nakṣatra* comprises three stars according to some and one according to others, and its principal star has been identified with δ Cancri in the constellation of Cancer (Praesaepe). This star cluster is usually visible to the naked eye as a misty nebular patch and is occasionally marked by the appearance of a new star or a nova. Fleet

suggests that, when the *Brāhmaṇa* observation was recorded, Jupiter was quite close to Praesaepe in which a new star appeared with an exceptional outburst producing great light in the highest heaven. "In short," observed Fleet, "In these two passages, certainly, I would find a distinct mention of a planet in the Vedas; the planet in this case being Bṛhaspati, Jupiter."[83] In support of his interpretation, Fleet also quoted *Ṛgveda* verse 5.54.13 referring to the occasional disappearance of the star-cluster Praesaepe.

Keith did not believe that the Vedic Hindus were aware of the planets. According to him their *nakṣatra* system was borrowed from some other nation. Although he admitted that Fleet's arguments were ingeneous he gave a different construction to the passages and concluded that the new evidence adduced by him did not really help towards providing the Vedic knowledge of the planets.[84]

The Vedic Calendar

In 1912 R. Shamasastry carried out an investigation of several passages in the *Saṃhitās, Brāhmaṇas* and *Sūtra* literature to understand the efforts made in the Vedic times to evolve a workable calendar.[85] The term 'Vedic Calendar', he admitted, would be an anachronism because clear references to a calendar were wanting in the Vedas proper; but such was not the case in the *sūtra* literature which clearly recorded various attempts made to evolve calendars, which could be appropriately designated 'sūtraic calendars'. Nevertheless, allusions to a calendar, he maintained, were not altogether wanting in the Vedas. These allusions are to be found in the frequent use of the term *ekāṣṭakā* day, which meant the eighth day of the dark half of the month of *Māgha,* marking the beginning of the new year. Moreover, there are distinct references to the thirteenth month used for purposes of intercalation so as to make the lunar reckoning agree with the natural time.

The onset of the *ekāṣṭakā* day is hailed in the *Atharvaveda* (III, 10) as—'Hither hath come the year, thy spouse, O sole Aṣṭakā, do thou provide our long lived progeny with abundance of wealth.' *Tāṇḍyamahābrāhmaṇa* (V. 9.2.) has it: "What is called the *ekāṣṭakā* (day) is the wife of the year; when the night of this day arrives, (Prajāpati) lies with her. Hence, commencing with the (true) beginning of the year, (sacrificers) observe the rite of initiation." These and similar other verses make it clear that the year, possibly solar, used to begin on the eighth day of the dark half of the month of Māgha. The *ekāṣṭakā* day, Shamasastry suggested, was a lunar day. The lunar year from one *ekāṣṭakā* to the other comprised 354 lunar days. There was also a *sāvana* year of 360 days commencing on the *ekāṣṭakā* day which consequently needed an adjustment of 6 days between these two kinds of years. This was done by means of intercalation.

The practice of intercalation through the introduction of a thirteenth month was as old as the *Ṛgveda*. *Rv.* i.25.8 states, "He who, accepting the rites (dedicated to him) knows the twelve months and their productions, and that which is supplementarily engendered *(upajāyate)*." The word *upajāyate* means, according to

Sāyana's commentary, 'the thirteenth or additional month which is produced of itself, in connection with the year'. The *Atharvaveda* (XIII, 3.8) explicitly mentions the thirteenth month *(trayodaśaṃ māsaṃ yo nirmimīte)*. In the Black *Yajurveda,* the thirteenth month is called a creeping month *(saṃsarpa)*, 'thou art the month of saṃsarpa; and thou art the receptacle of sin' (i.4.14). These and similar references in the *Brāhmaṇas* make it abundantly clear 'that the Vedic poets kept a calendar with far more scientific precession than we are pleased to credit them with.' Shamasastry argued that the idea of a thirteenth month could not have dawned upon the Vedic poets unless they had been familiar with the true lengths of several kinds of years. The intercalation by a thirteenth month was preceded by the practice of adjusting the two kinds of year by introducing sets of intercalary days, e.g. 9,11,12,21, etc.

The *Nidāna-sūtra* of the *Sāmaveda* provides evidence of different types of years and of different Vedic schools practising intercalation in various ways. In fact, the *sūtra* uses the term *gavām ayana* in the sense of a year containing a number of intercalated days inserted either in the middle or at the end. Literally the term means 'cow's walk', i.e. a series of intercalary days. Thus :

(a)	Synodic lunar year of 354 days Sidereal solar year of 366 days	*dvādaśāha* or period of 12 days to be added to every lunar year.
(b)	Sidereal lunar year of 351 days (13 months of 27 days each) *Sāvana* year of 360 days	9 intercalary days to be added.
(c)	*Sāvana* year 360 days Solar year of $365\frac{1}{4}$ days	21 days to be added to every fourth sāvana year.

Besides, there were a few other types of years, e.g. a sidereal lunar year of 324 days (27×12), sidereal solar year of 366 days and pseudo solstitial year of 378 days. Of the various forms of calendars used in the Vedic times, the principal ones appear to be the following :

(a) The sidereal lunar year of 351 days, with 9 or 15 days intercalated according as it was to be adjusted to the *sāvana* year of 360 days or to the sidereal year of 366 days.

(b) The synodic lunar year of 354 days intercalated with 12 days as stated above.

(c) The cycle of three *sāvana* years each of 360 days, intercalated with 18 days in every third or fourth *sāvana* year, for adjustment to the sidereal solar year of 366 days.

Berriedale Keith agreed with Shamasastry that there was a Vedic year of 360 days vouched for by the *Ṛgveda* and further that the Vedic Hindus were aware of the need for intercalation and practised it for keeping the seasons in check. 'The most

that we can say on this head is that there are traces of a tendency to intercalate a month every fifth or sixth year, but that even for this the evidence is not cogent.'[86] He disagreed with Shamasastry's interpretation of *gavām ayana* as an intercalary period made up of any number of intercalary days, because this sense of the term was not hinted at by any ancient authority.

Kaye's Hindu Astronomy, Āryabhaṭa Studies By P. C. Sengupta and Eugene Clark

During the first three decades of the present century, George Rusby Kaye generated further interest in the study of mathematics and astronomy in ancient and medieval India. His researches in astronomy concerned spherical astronomy, Vedic astronomical dieties, Jai Singh's observatories and related subjects. In a publication of the Archaeological Survey of India he carefully described the metal and masonry instruments associated with the observatories built by the astronomer king,—astrolabes among the metal instruments, and *Samrāṭ yantra, Jai prakāś, Rāmyantra, digaṃśa yantra, nāḍivalaya yantra, ṣaṣṭyaṃśa yantra, rāśi valaya* and a few others. In another publication of the same Survey he traced the development of Hindu astronomy, noticing the labours of early investigators such as Cassini, Le Gentil, Bailly, Laplace, Davis, Jones, Bentley and Colebrooke; pre-scientific astronomy in the Vedic *Saṃhitās, Jātakas,* epics and the *Purāṇas;* special topics such *nakṣatras,* solstices and equinoxes, precession, Jupiter's cycle; a number of prominent astronomers like Puliśa, Āryabhaṭa, Varāhamihira and Brahmagupta; mathematical astronomy involved in such topics as ascensional difference, epicycles and equations of centre, parallax, and eclipses. Despite the merit of Kaye's diligent researches and prolific writings his works suffered somewhat for his strong bias in favour of foreign influence in the development of astronomy and mathematics in India.

It was no wonder that the challenge thrown up by the writings of Kaye should be taken up by Indian as well as some foreign scholars. From about the middle of the twenties Bibhuti Bhusan Datta, Sukumar Ranjan Das, Prabodh Chandra Sengupta, Walter Eugene Clark and a few others started a series of investigations on ancient Indian astronomy. Datta dealt with the question of two Āryabhaṭas,—the elder Āryabhaṭa and his younger name sake of Kusumapura, which influenced Kaye, Smith and others to advance doubts about the authorship and date of composition of *Gaṇita,* a section of *Āryabhaṭīya.* He compared al-Bīrūnī's references to passages attributed to Āryabhaṭa with those of the extant *Āryabhaṭīya,* noticed the work of *Ārya-siddhānta* by an author of the same name whom Dikshit and Sewell placed in A.D. 950, and proved the error of Kaye in attributing the *Gaṇita* section of the *Āryabhaṭīya* to Āryabhaṭa of Kusumapura and placing the latter in the 10th century A.D.

Intensive researches on Āryabhaṭa developed after the publication by Kern of the *Āryabhaṭīya* with the commentary by Parameśvara. The mathematical chapters of the work were studied by Rodet, Kaye, Datta and Ganguli. The whole work was translated into English by P. C. Sengupta in 1927 and Walter Eugene Clark in 1930. Sengupta made a special study of Āryabhaṭa's astronomical system and

translated in English, with a short introduction, Brahmagupta's *Khaṇḍakhādyaka,* based on Āryabhaṭa's mid-night system. He further developed the idea that Āryabhaṭa was possibly the father of Indian epicyclic astronomy. According to him, astronomer Pradyumna made a special study of the superior planets, while Vijayanandin likewise studied the peculiarities of the inferior planets. Both these astronomers flourished before the time of Āryabhaṭa and did for Indian astronomy what Hipparchus had done for the Greek. Āryabhaṭa utilized the work of Pradyumna and Vijayanandin, determined afresh some of the astronomical constants, and constructed the Indian epicyclic astronomy, 'as far as it can be called so', which inspired later Indian astronomers. 'Thus the position of Āryabhaṭa in India,' observed Sengupta, 'was the same as that of Ptolemy in Alexandria. This explains the reason why Āryabhaṭa is held in so great esteem by all Indian writers.'[88] Sukumar Ranjan Das, in a series of papers of an expository nature, discussed such problems of Indian astronomy as parallax, precession and libration of the equinoxes, lunar and solar eclipses, astronomical instruments, the Jaina calendar, and motion of the earth as conceived by ancient Indian astronomers.

AL-ANDALUSĪ'S CATEGORY OF NATIONS

In 1935, Regis Blachére translated into French Sā'īd al-Andalusī's *Kitāb Ṭabakāt al-Umam (Livre des Catégories des Nations).* The text was produced in Spain in the eleventh century and recorded some old Arabic tradition about Indian astronomy. In describing various categories of nations and their aptitudes in arts and sciences, in other words in intellectual pursuits, Sā'id stated that only eight nations were interested in, and comprehended, science. These eight peoples were the Hindus, the Persians, the Chaldeans, the Jews, the Greeks, the Romans, the Egyptians and the Arabs. In this list of eight nations which cultivated the sciences, he placed the Hindus at the head because 'Les Indous, entre toutes les nations, à travers les siecles et depuis l'antiquité, furent la source de la sagesse, de la justice et de la modération. Ils furent un peuple doné de vertus pondératrices, créature de pensées sublimes, d'apologues universels, d'inventions rares et de traits d'esprit remarquables'.[89] In astronomy he recorded the tradition of *Sindhind, Arjābhar,* and *Arkand,* the three works among many, known to the Arabs, of which only the first one, e.g. the *Sindhind* had been transmitted to the Arabs in a perfectly intelligible form. According to him, *Sindhind* meant 'infinite time' ("temps infini"); this work was adopted and lent itself to the preparation of astronomical tables by a number of Arab astronomers such as Muḥammad ibn Ibrāhīm al-Fazārī, Ḥabas ibn 'Abd Allah al-Bagdādī, Muḥammad ibn Mūsā al-Khwārizmī, al-Ḥusain ibn Muḥammad known by the name of Ibn al-Adamī. Sā'id also faithfully recorded the tradition of the arrival in Khalif al-manṣūr's court of an Indian astronomer versed in the calculations followed in the *Sindhind* and equipped with a copy of the book containing twelve chapters, dealing with astronomical equations *(ta'ādil),* sine lines *(karadajāt)* and other subjects. Al-Manṣūr ordered an Arabic translation of the Sanskrit text, and charged al-Fazārī with the task, which he accomplished under the title *as-Sindhind al-Kabīr* (the *Great Sindhind*). This work was later on abridged by al-Khwārizmī who dealt with the mean longitudes *(awsāt)* after the *Sindhind,* but introduced the methods of the Persians and

of Ptolemy in some astronomical matters. Even in his time, his contemporaries who had a preference for the *Sindhind* held the work in lively admiration. In Sā'id's time *Sindhind* continued to be useful to those who desired to cultivate astronomy (Les contemporains, partisans du Sindhind, marquérent toutefois une vive admiration pour ce traité et eu firent les plus grandes éloges. Ce livre n'a cessé de servir à ceux qui cultivent l'astronomie, jusqu'à nos jours).[90]

Otto Neugebauer's Contribution

In the fifties Otto Neugebauer, already distinguished for his work on cuneiform mathematical texts, published a series of papers in quick succession, which added a new dimension to researches in the history of Indian astronomy. Upon the appearance in 1953 of Louis Renou and Jean Filliozat's *L'Inde classique—Manuel des Études indiennes,* Neugebauer produced an essay review of the work, particularly of its articles on astronomy, drawing attention to the failures of sanskritists and orientalists to take note of important developments in other areas of great significance to Hindu astronomy.[91] Even after more than half a century the basic material for the general evaluation of the historical position of Hindu astronomy, he commented, was substantially the same as recorded by Thibaut in his 'Astronomie, Astrologie und Mathematik' in the *Grundriss*. This was because the relevant literature lay 'almost completely beyond the normal horizon of Sanskrit scholarship'. Greek and Babylonian influences on Hindu astronomy had been occasionally talked about more or less speculatively, but the half century provided some definite clues which had been ignored. Thibaut realized the importance of the ratio of 3:2 as longest to the shortest day in the *Pañcasiddhāntikā*, but hesitated to admit of its Babylonian origin unless the existence of such a ratio in Babylonian materials was actually demonstrated. This demonstration was provided by Kugler a year later in his *Babylonische Mondrechnung*. A few years later Franz Boll discovered in Greek astrological manuscripts fragments of tracts by one Babylonian astrologer of the name of Teucros, which passed into the writings of Abu Ma'shar; these fragments concerned constellations or spheres and were closely related to those known from Persian, Indian and Greek sources. The same constellations with their decans were identified by A. Warburg in the fifteenth century frescos in the Palazzo Schifanoja of Borso. This discovery meant that 'all the major steps of a complete cycle of transmission of astrological lore and its transformation from Hellenistic Egypt to India and back to Europe had been established.'

Thibaut had already noted in the *Pañcasiddhāntikā* the Babylonian fundamental period relation for Jupiter. Twentyfive years later P. Schnabel, in a short note in the *Zeitschrift für Assyriologie* (1924), showed that the periods of Saturn and Venus also agreed with those given in the Babylonian planetary texts of the Seleucid period. This was the background of Neugebauer's own interest in *Varāha's Pañcasiddhāntikā*, for he stated, "Matters rested at this point for another 25 years until I realized that the methods described by Thibaut in his summary of the 'third period' (*Vaśiṣṭha-siddhānta* and *Vākyam)* were identical with methods represented by two Greek papyri

of the Roman imperial period and eventually with procedures of Babylonian astronomy, exactly as in the case of Kugler's and Schnabel's identifications' Earlier in his *Exact Science in Antiquity,* Neugebauer had made similar observations,"....we stand today only at the beginning of a systematic investigation of the relations between Hindu and Babylonian astronomy, an investigation which is obviously bound to give us a greatly deepened insight into the origin of both fields.....The fact that a close relationship between Babylonian linear methods and sections of the *Pañcasiddhāntikā* can be established is only one facet of the general problem of the evaluation of the role of Hindu astronomy in the history ofscience.....We have here an early historical report on source material which is no longer extant, or at least no longer extant in exactly the same form. On the other hand Varāhamihira is also one of the main sources of al-Bīrunī's report on Hindu astronomy and astrology, written about A.D. 1030. Consequently Varāhamihira occupies a central role for the study of Hindu astronomy."[92] This explains the publication by Neugebauer and Pingree of a new and critical edition of the *Pañcasiddhāntikā* with an English translation and commentary in 1970-71.

One of the early efforts of Neugebauer was directed to trace Babylonian linear and arithmetical methods in the computational procedures of calendar makers of South India for determining the times of occurrences of eclipses, recorded by Le Gentil and John Warren and already mentioned before.[93] Warren obtained his information from a calendar maker 'who showed him how to compute a lunar eclipse by means of shells placed on the ground, and from tables memorized by means of certain artificial words and syllables'. The Tamil informer (Sashia) computed for Warren the circumstances of the lunar eclipse of 1825 between May 31 and June 1. The errors were–4′ for the beginning, -23′ for the middle and -52′ for the end. The surprising thing was not the accuracy of the computational procedures, but the continuance of a tradition first found in the Seleucid cuneiform texts dated 2nd or 3rd century B.C., Roman sources of the 3rd century A.D., and Varāha's report of the 6th century A.D. Neugebauer suggested that the thriving Indo-Roman maritime trade during the first few centuries of the Christian era possibly brought about the transmission of the procedures to astronomers and almanac makers of South India. He gave a full account of the procedures with the help of Warren's tables and his own reconstructions for which the original paper must be consulted. Three years later B. L. vander Waerden examined the same materials of Warren and Le Gentil and explained some of the gaps left unexplained by Neugebauer, which will be discussed in what follows.

In another paper Neugebauer discussed the transmission of planetary theories and gave an excellent exposition of the eccentric-epicyclic model.[94] If the geometry of the true positions of the planet be worked out by first applying the apsis *(manda)* correction and then the conjunction *(śighra)* one without making any approximation, the correction δ being the difference between the true and mean longitudes $(\lambda—\lambda)$, will be given by :

$$\sin \delta = \frac{\gamma \sin \gamma - e \sin \alpha}{\sqrt{(\gamma \sin \gamma - e \sin \alpha)^2 + (R + e \cos \alpha + \gamma \cos \gamma)^2}}$$

where α = anomaly, γ = argument, e = eccentricity, r = radius of the *sighra* epicycle, and R = radius of the deferent circle. Clearly, the equation involving both the corrections is unusable for tabulation for which the *śighra* and *manda* corrections, σ and μ respectively are computed separately by introducing certain approximations. One approximation introduced by the Hindu astronomers was to transfer the position of the mean planet as modified by the *manda* correction to the deferent circle and then draw the *śighra* epicycle with this transferred point as centre. The second approximation is to ignore the eccentricity for the *manda* correction compared to the large value of the deferent radius, but to retain the value of the *śighra* epicycle radius while computing the *śighra* corrections, which leads to the following corrections :—

For *manda* correction,

$$R \mu = e \sin \alpha$$

For *śighra* correction,

$$\sin \sigma = r \sin \gamma$$

$$\text{where } h = \frac{h}{\sqrt{(R + \cos \gamma)^2 + (\gamma + \sin \gamma)^2}}$$

Neugebauer remarked that there was 'no compelling reason to treat the effect of the eccentricity with so much less accuracy than the effect of the anomaly, except for the fact that usually e is smaller than r'. The followers of Āryabhaṭa, however, did not insist on this approximation and retained the eccentricity in computing *manda* corrections. To neutralize the errors due to the aforesaid approximations the Hindu astronomers developed a procedure in which the *manda* and *śighra* corrections were not directly added to the mean longitude, but the corrections were introduced in stages by applying half the values of μ and σ. These procedures by half are given in all astronomical texts, of which Neugebauer has furnished an elegant geometrical exposition. The same procedure was adopted by al-Khwārizmī in constructing his planetary tables. Neugebauer also noted the Indian practice of employing variable epicycles for both these corrections, but left it unexplained.

The importance of al-Khwārizmī in relation to Indian astronomy has been recognized for a long time in as much as he syncretized Hindu mathematical and astronomical knowledge with that of the Greek and played a notable part in the second phase of the Arab intellectual revival. Al-Khwārizmī's astronomical tables, in Arabic original, have not come down to us, but survived in a Latin translation of one of its edited versions by the Spanish astronomer Maslama al-Majriṭī (about A.D. 1000). The Latin translation was probably done by Adelard of Bath. At the beginning of the present century A. Bjornbo and R. Besthorn prepared a critical edition of the text with notes and H. Suter prepared an elaborate commentary, resulting in the publication in 1914 of *Die astronomischen Tafeln des Muḥammed ibn Mūsā* from Copenhagen. Suter did not attempt to translate the Latin text in any of the modern European languages because 'it would be of little use to anyone who is not familiar with ancient and medieval astronomy'. Nearly fifty years later Neuge-

bauer rendered a signal service to the history of Arabian and Hindu astronomy by producing an English translation and commentary of the Latin version of al-Khwārizmī's tables as edited by Suter and adding supplementary materials from a manuscript found in the Corpus Christi College, Oxford. Majriṭī's edition, according to Neugebauer, appears to be somewhat removed from the original *zij* of al-Khwārizmī; a commentary on the tables by al-Muṭannā (c. 10th century A.D.) latinized by Hugo Sanctallensis probably used a more coherent treatise.

Be that as it may, the present English version makes it abundantly clear how the rules from Hindu astronomical treatises were utilized and juxtaposed with those from the works of Ptolemy and Theon. In the very introductory paragraph al-Khwārizmī refers to the prime meridian of Arin (Ujjayinī) as follows: "To describe all regions of the earth and to establish all (local) times would be tedious and unfeasible since, for innumerable times and for boundless regions, the meridians have been recorded (with respect to) Arin,. ."[95] In chapter 7 on the mean positions of each planet we are told that such positions are given in the table for the locality of Arin, and a longitude correction will have to be made if we want to find them for any other locality. The rules for making apsis and conjunction corrections to mean longitudes of the three superior planets—Mars, Jupiter and Saturn are given in chapter 10. Before describing the geometrical epicyclic-eccentric models and developing the equations, Neugebauer opens this commentary as follows:—"Al-Khwārizmī's procedure for finding the true longitude of a planet for a given moment *t* is based on Hindu methods known to us from the *Sūrya-siddhānta, Khaṇḍakhādyaka* etc..... It is in any case certain that the underlying model was not influenced by Ptolemy's great innovation of a motion regulated from an eccentric equant. The procedure followed by al-Khwārizmī, is a slight modification of the procedures we know from Hindu sources."[96] The rules for finding the latitudes of three superior and two inner planets were compared to those of the *Āryabhaṭīya, Khaṇḍakhādyaka,* and the *Sūrya-siddhānta* and found to be based on the same model and formulae. This is also true of the calculations of ascensional difference. Al-Khwārizmī's eclipse tables would also be understood in the light of rules given in the *Khaṇḍakhādyaka,* which, set up in the modern mathematical language, revealed a close identity with the method given by Kepler for the calculation of parallaxes in latitude and longitude.[97]

Neugebauer's original insight into the historical position of Varāhamihira and his *Pañcasiddhāntikā* and David Pingree's scholarship in Sanskrit astronomical literature formed a happy combination in the production of a new and critical edition of the text, with an English translation and an excellent commentary embodying a good deal of recent researches on the subject. In their introduction to part I providing text and translation, the authorship question of the five *siddhāntas* has been further clarified. Varāha's *Paitāmaha-siddhānta* was derived from Lagadha's *Jyotiṣavedāṅga* and not from the *siddhānta* bearing the same name and forming part of the *Viṣṇudharmottarapurāṇa.* Three *Vaśiṣṭha-siddhāntas* have been recognized, e.g. (1) one *Vaśiṣṭha-siddhānta* mentioned by Sphujidvaja in his *Yavanajātaka* and dated around A.D. 269/70, (2) a *Vasiṣṭhasamāsa-siddhānta* abridged from an older and original work possibly around A.D. 499, from which Varāha summarized the lunar theory, the solar theory,

the theory of *nakṣatras* and *tithis,* and the gnomon problems, and (3) a *Vaśiṣṭha siddhānta* attributed to Viṣṇucandra and compiled probably in the latter half of the sixth century A.D.[98] Sphujidhvaja's *Vaśiṣṭha* contained an earlier adaptation of the Babylonian planetary theory and the *Vaśiṣṭhasamāsa-siddhānta* dealt with Babylonian planetary theories and other astronomical elements more elaborately. Viṣṇucandra's version known mainly from Brahmagupta's *Brāhmasphuṭa-siddhānta* is a different type of work based on '*ārdharātrika* (Lāṭa) and *audayika (Āryabhaṭīya)* elements with some from Vijayanandin'. We have already discussed Thibaut's comments on this work. The *Romaka-siddhānta* is known in two versions, e.g. Varāha's account in chapters I, 8-10, III, 34-35 and VIII, based on Lāṭa's edition, and a work by Śrīṣeṇa, known from Brahmagupta. The Greek elements of the former have long been recognized, and the authors suspect that it appeared in Western India during the Śaka or Gupta rule. Śrīṣeṇa's *Romaka-siddhānta* was based on elements borrowed from Lāṭa, Vaśiṣṭha, Vijayanandin and Āryabhaṭa. For Varāha's *Pauliśa-siddhānta,* Lāṭa's commentary was again the source obviously based on Alexandrian-Greek sources. But Paulus Alexandrinus, the astrologer-author of *Eisagog* (A.D. 378) who was not known to have written on astronomy could not be the same as Puliśa, the author of this *siddhānta.* From Pṛthūdakasvāmin, Utpala and al-Bīrūnī, we know of another *Pauliśa-siddhānta,* which developed an *ārdharātrika* system and was written in the eighth century A.D. The authorship of the *Sūrya-siddhānta* as summarized by Varāha has been left an open question. Neugebauer and Pingree believe that Lāṭa was the author of the work on a tradition referred to by al-Bīrūnī, although Varāhamihira does not refer to Lāṭa in connection with this work.[99] It is admitted that the parameers tof this *Sūrya-siddhānta* conformed to those of the *ārdharātrika* system promulgated by Āryabhaṭa, and further that Lāṭadeva, Pāṇḍurangasvāmin and Niḥśanka were all pupils of Āryabhaṭa. Why this senior esteemed teacher whose system was adopted for working out the most accurate of the five *siddhāntas* should not be given the credit of authorship is not understood.

In addition to the sources mentioned above, particularly Lāṭa and Āryabhaṭa, Varāhamihira was in all probability influenced by the teachings of his father Ādityadāsa of an Iranian (Maga) lineage. Varāha mentions a Yavana teacher, possibly a Sasanian astronomer. Furthermore, what was the role of Siṃha, Pradyumna and Vijayanandin mentioned by Varāhamihira as also by Brahmagupta? Clearly the sources are far from being fully understood.

Despite its historical position the *Pañcasiddhāntikā* appears to have exercised little influence on later astronomical literature in India. Brahmagupta and al-Bīrūnī who again depended on the former carried some notices, and Śatānanda in the eleventh century utilized Varāha's *Sūrya-siddhānta* in writing his *Bhāsvati.* Some references are found in Pṛthūdakasvāmin, Utpala, and Āryabhaṭa's scholiasts Parameśvara and Nīlakaṇṭha. That is about all. Curiously enough the *Pañca-siddhāntikā* tradition turned up in China in the eighth century astronomical work *Chiu-Chih-li* by Ch'u-Ta'n Hsi-ta (A.D. 718). It is well known that during the first few centuries of the Christian era a number of Buddhist scriptures with Indian astronomical content were translated into Chinese. These early tracts probably

taught Indian astronomy of the pre-siddhāntic period. The scientific astronomy characteristic of the *siddhāntas* was introduced to China in the Thang period by the three schools of Indian astronomy represented by Kāśyapa, Gautama and Kumāra.[100] The most prominent of them was probably Hsi-ta of the Gautama school, who prepared the *Chiu-Chih-li* (*nava-graha* calendrical astronomy). The text discussed a number of Indian mathematical rules as applicable to astronomy, contained a section on numerals, another section on sine tables in connection with the prediction of moon's positions, and so on. The values of the sine table agreed with those given in the *Āryabhaṭiya* and the *Sūrya-siddhānta*. Neugebauer and Pingree have now identified in the *Chiu-Chih-li* the following elements of the *Pañcasiddhāntikā* :

"I. The computation of the ahargaṇa (pp. 499-502). The Chiu-chih-li uses formulas which are the equivalents, with suitable sub stitutions for the new epoch, of the formulas in I, 9-11 (Romaka).

II. The computation of the mean longitudes of the Sun, lunar apogee, and lunar anomaly (pp. 502-505). The rules in the Chiu-chih-li are based on the parameters in IX, 11-12 (Sūrya).

III. The computation of the solar and lunar equations (pp. 506-511). This passage is derived from IX. 7 (Sūrya).

IV. The computation of the length of day-light (pp. 511-513). The Chiu-chih-li depends on III, 10 (Pauliśa).

V. The determination of the daily progress of the Moon (p. 514). See III, 9 (Pauliśa).

VI. The determination of the daily progress of the Sun (p. 515). See III, 17 (Pauliśa).

VII. The computation of the nakṣatra, nakṣatra saṅkrānti, and tithi (pp. 515-518). See III, 16 (Pauliśa).

VIII. The computation of the longitude of the lunar node (pp. 521.522). See III, 28 (Pauliśa).

IX. The computation of lunar latitude (pp. 526-527). See IX, 6 (Sūrya).

X. The computation of the duration of a lunar eclipse (pp. 528-529). See VI, 3 (Pauliśa ?).

XI. The computation of the magnitude of a lunar eclipse (pp. 529-530). See VIII, 18 (Romaka).

XII. The computation of the duration of totality of a lunar eclipse (pp. 530-531). See VIII, 16 (Romaka)."[101]

The *Pañcasiddhāntikā's* influence among the circles of astronomers and calendar-makers in South-East Asia can be guessed from the fact that one of the two rare manuscripts of the text was copied in Stambhatīrtha (Cambay) in A.D. 1616.

The commentary given in part II is a model of modern mathematical treatment of ancient astronomical rules and procedures. Clearly the same technique which Neugebauer developed for al-Khwārizmī's astronomical tables has been followed. The sinusoidal relationships in equations of centres recorded in the *Romaka* and *Pauliśa* without rules, the full explanation of the double epicyclic model underlying the computation of planetary equations as per the *Sūrya-siddhānta* (ch. XVI), the exposition of Vaśiṣṭha's theory of planetary motions and planetary phases in keeping with Babylonian methods (ch. XVII, first 60 verses), have been very clearly and lucidly presented. The authors did not claim to have solved all the problems with this difficult text. Some of the interpretations due to the authors have been called into question, to which a further reference will be made in what follows, but their hope 'that future historians of Indian astronomy will find this volume a useful tool' has already started to bear fruit.

Mahābhāskarīya and other Works

While some of the Western scholars were thus busy in demonstrating the links of Indian astronomy to West Asian and Graeco-Alexandrian traditions, Indian scholars came forward with renewed interest to publish critical editions, translations and annotations of important astronomical source materials. In 1945 Balavantaraya Apte, edited the *Mahābhāskarīya* of Bhāskara I with Parameśvara's commentary *Karmadīpikā*. In 1957 T. S. Kuppanna Sastri brought out another edition with the commentary of Govindasvāmin in the Madras Government Oriental Series; although he did not undertake to translate the text, he produced a valuable introduction, drawing attention to the practice of the Āryabhaṭan school to retain the unabridged value of the hypotenuse in making *manda* corrections and to the *ārdharātrika* system briefly given towards the end of the treatise. The want of annotated English translations of both the *Mahābhāskarīya* and *Laghubhāskarīya* was removed by Kripa Shankar Shukla in 1960. Bhāskara I's (c. A.D. 600) importance in the history of Indian astronomy need hardly be overestimated inasmuch as he was a follower of Āryabhaṭa I, a contemporary of Brahmagupta and wrote besides the two works mentioned above a *bhāṣya* on the *Āryabhaṭīya*. In his commentary Shukla discussed in detail Bhāskara I's treatment of Āryabhaṭa's epicyclic theory and his method of determining the distance of the true planet from the centre of the deferent by successive approximations *(asakṛtkarma)*.[102]

Brahmagupta's *Khaṇḍakhādyaka*, with the commentary of Bhaṭṭotpala, was critically edited, translated and annotated by Bina Chatterjee in 1970, which supplemented the earlier editions of Probodh Chandra Sengupta (with an English

translation and notes) and Babua Misra (text only). Bina Chatterjee's another work *Śiṣyadhīvṛddhida Tantra* of Lalla, with the commentary of Mallikārjuna Sūri and English translation and mathematical notes, was posthumously published in 1981. K. V. Sarma edited and/or translated a number of works by Parameśvara, e.g. *Dṛggaṇita, Goladīpikā, Grahṇāṣṭaka, Grahaṇāmaṇḍana* and *Grahaṇa-nyāyadīpikā*, each one a small astronomical tract. He also edited, with a good introduction in each case, Nīlakaṇṭha Somayāji's *Siddhānta-darpana, Golasāra, Tantrasaṅgraha,* and *Jyotirmīmāṃsā*, Haridatta's *Grahacāranibandhana,* Mādhava's *Venvāroha* and Sundarāja's *Vākyakaraṇa*. In his *History of the Kerala School of Hindu Astronomy* (1972), he briefly noticed the life and works of a large number of medieval astronomers based in Kerala, e.g. Govindasvāmin (c. 800-850), Śaṅkaranārāyaṇa (c. 825-900), Sūryadeva Yajvan (1191—c. 1250), Mādhava of Saṅgamagrāma (c. 1340—1425), Parameśvara of Vaṭaśreṇī (c. 1360—1455), Dāmodara (c. 1410—1510), Nīlakaṇṭha Somayāji (1444—1545), Jyeṣṭhadeva (c. 1500—1610), Putumana Somayāji (1660—1740) and several others and gave a detailed bibliography of Keralan astronomers and their works. Shukla and Sarma translated the *Āryabhaṭīya* with explanatory notes in 1976; at the same time the former produced a critical edition of the text with commentaries of Bhāskara I and Someśvara and the latter another edition of the same with the commentary of Sūryadeva Yajvan. The Indian Institute of Astronomical and Sanskrit Research published, under the editorship of Ram Swarup Sharma, *Brāhmasphuṭa-siddhānta* with an elaborate introduction, *Vaṭeśvara-siddhānta* with Sanskrit, Hindi and English commentary, and Jagannātha's *Samrāṭ-siddhānta,* being a Sanskrit translation from an Arabic version of Ptolemy's *Almagest.*

The Osmania Oriental Publications Bureau rendered invaluable service to the cause of the study and researches in the history of astronomy by editing and publishing al-Bīrūnī's *Al-Qānūnu'l-Masūdī,* an encyclopaedic work of considerable significance to Indian astronomy. The Bureau's other publications include *Rasā'il al-Bīrūnī* (Bīrūnī's tracts) which contains three dissertations on the questions of shadows, the Indian rule of three and calculations of the chords of the circle; *Kitāb al-'amal bi'l-aṣṭurlāb* of aṣ-Sufi with an introduction by E. S. Kennedy and Marcel Destombes; and the *Rasā'il Abū Naṣr ila'l-Bīrūnī* containing 14 tracts of Abū Naṣr on questions of mathematics, astronomy, astrolabe and miscellaneous matters. Sayyid Rizvī published in the *Islamic Culture* the text and translation of al-Bīrūnī's *Ghurrat al-Zījāt,* with critical notes; the *Ghurrat* was Bīrūnī's translation of Vijayānanda's *Karaṇatilaka.* Al-Bīrūnī's another important tract on the determination of latitudes and longitudes of cities, the *Kitāb taḥdīd nihāyāt al-amākin* etc., was published in the *Revue de l' Institut des Manuscrits Arabes,* Cairo, an English translation of it, with modern commentaries, being produced by Jamīl 'Alī.

YAVANJĀTAKA AND OTHER WORKS OF DAVID PINGREE

David Pingree's approach to Hindu astronomy appears to have been prompted by Neugebauer's transmission theory. In connection with his study of Tamil astronomy Neugebauer noted a basic dualism between geometric and arithmetical methods in the development of Hindu astronomy, a dualism that also characterized

early Greek astronomy. "Both components", he remarked in his review of *l'Inde classique*, "are of much earlier date than the influence on India which was carried, in all probability through Hellenistic astrology which reached its full development in Alexandria during the first centuries A.D." Hitherto such views were based on papyrus fragments and surmises. In 1959 Pingree reported briefly on a Greek linear planetary text written in Sanskrit, which provided a definite evidence of Babylonian methods and parameters in an astrological context.[103] The text in question is the *Yavanajātaka* of Sphujidhvaja, dated A.D. 269/270, and contains in its last chapter 'astronomical instructions' intended to improve upon, or substitute for, those of the *Vaśiṣṭha-siddhānta*. Fragments concerning the movements in arcs of Jupiter, Mars, and Saturn are quoted, their translations given, and compared with Babylonian elements. Pingree concluded, "..for the superior planets it has been demonstrated that the methods in use among those Greek astrologers who transmitted their learning to India in the second century after Christ were still closely related to those developed in Mesopotamia in the Seleucid period."

In 1978 Pingree's *Yavanajātaka of Sphujidhaja*, with edited Sanskrit text, English translation and commentaries, appeared from the Harvard University Press, in which these planetary elements have been fully given along with those from Babylonian cuneiform texts, as follows :—"The significant ("Greek-letter") phenomena referred to in the theory of the superior planets are:

Γ = first visibility in the East = *udaya*
Φ = first stationary point = *sthitva*
Θ = opposition
Ψ = second stationary point
Ω = last visibility in West = *asta*
$\Phi \rightarrow \Psi$ = retrogression = *vakra*

Jupiter

Javanajātaka	*Babylonian* *slow*	*medium*	*fast*
$\Gamma \rightarrow \Phi$ 16°	16;15°	18;16,52,30°	19;30°
$\Phi \leftarrow \Psi$ —8°	—8;20°	—9;22,30°	—10°
$\Psi \rightarrow \Omega$ 21°	15;50°	17;48,45°	19°
$\Omega \rightarrow \Gamma$ 6;15°	6;15°	7;1,52,30°	7;30°
35;15°	30°	33;45°	36°

Mars

Yavanajātaka	*Babylonian* System 1	System 2
$\Gamma \rightarrow \Phi$ 162° in 288 tithis	162;40° in 280 tithis	162;24° in 275; 37 tithis
$\Phi \rightarrow \Psi$ — 34°	191;20°	$\Phi \rightarrow \Omega$ 157°
$\Psi \rightarrow \Omega$		89;19°
$\Omega \rightarrow \Gamma$ 88;30°		
		408;43°

With reference to $\Phi \rightarrow \Psi$, the arc of retrogression, where Sphujidhvaja has $-34°$ it is to be noted that $\Phi \rightarrow \Omega$ in system 2 (157°) minus $\Psi \rightarrow \Omega$ in system 1 (191;20°) equals -34; 20°. This is, in fact, much too high.

"Sphujidhvaja should, of course, have given the time-intervals between the occurrences of all the Greek-letter phenomena for all the planets for his presentation to have had a practical use.

		Saturn		
Yavanajātaka			*Babylonian*	
		fast	*slow*	*time-intervals*
$\Gamma \rightarrow \Phi$	8;15° in 112 tithis	9°	7;30°	120 tithis
$\Phi \rightarrow \Psi$	−8° in 100 tithis	−8°	−6;40°	112; 30 tithis
$\Psi \rightarrow \Omega$	—	9;3,45°	7;33,7,30°	120 tithis
$\Omega \rightarrow \Gamma$	—	4°	3;20°	—
	12°	14;3,45°	11;43,7,30°	

In Sphujidhvaja, before the remainder of Saturn was lost, it should have been stated that $\Psi \rightarrow \Omega$ is about 8° in 120 tithis, and $\Omega \rightarrow \Gamma$ about 3;45° in 40 tithis."[104] Similar data for inferior planets are given which have likewise been explained.

The linear planetary theory is cursorily discussed in 62 verses of the last chapter 79 of the *Yavanajātaka*. This is obviously a difficult chapter to follow and must be learnt thoroughly before one is able to practise astrology according to the teachings of the text. Pingree has given a masterly exposition of the various verses establishing their connections with ancient Greek and Latin astrologers like Antiochus, Atheniensis, Critodemus, Dorotheus Sidonius, Firmicus, —52 names have been given, as well as with later Indian astrologers who used this text or its teachings. Here we shall only refer to a few observations of Pingree with regard to the zodiac introduced in the few opening verses of chapter 1 because it has been known for a long time that the twelve signs of the zodiac were introduced into Indian astronomy through astrological sources of foreign origin. In presenting the zodiacal scheme, its three main aspects, e.g. iconography of the signs, their melothesia, and their topothesia, are described. Iconographically Sphujidhvaja's zodiac contains several features common to the Hellenistic one, some of which were of Egyptian-cum-Hellenistic origin, e.g. the man and woman depiction in the Mithuna with the club and the lyre agreeing with the Egyptian pair Shu and Tefnut; the figure of a maiden standing in a boat and holding a torch representing Virgin etc. Pingree believes that the zodiac was possibly unknown in india before Yavaneśvara.[105]

The Egyptians had developed the idea of correlating different signs of the zodiac with specific parts of the human body so as to produce a scheme of zodiacal melothesia. Out of this idea originated the erect cosmic man and the theory of microcosm and macrocosm in medical schools which became widespread in the

ancient world. Sphujidhvaja's scheme in which Aries is represented by the head of the human body, Taurus by mouth and neck, Gemini by shoulders and arms, Cancer by chest, Leo by heart, Virgo by belly and so on was derived from Egyptian concepts.

The appearance of Sanskrit works of the class of *Yavanajātaka* also fits in well with the early political and economic history of India. During the Achemenid occupation (500 B.C. to 230 B.C.) and later unsettled conditions marked by the incurisons of the Greeks, the Śakas, the Pahlavas, and the Kuṣāṇas, Indian astronomy, Pingree conjectures as others did before him, was introduced to Babylonian methods, e.g. some of the elements of the luni-solar calendar of the *Vedāṅga Jyotiṣa,* including the concept of *tithi,* variation of day-length etc. At the beginning of the first century A.D., one branch of the Śakas, the Kṣaharātas, established a kingdom in West India with Mīnanagara as their capital and Broach (Gk. Barygaza) as their main trading post between India and the Mediterranean countries. This branch succombed to another Śaka dynasty, the Western Kṣatrapas, of which the greatest king Rudradaman I ruled between A.D. 130 to 160 over a vast empire extending up to Kausambi in the north and Kalinga in the east. The Kṣatrapas were interested in astronomy, established their capital at Ujjayinī and soon raised this city as the foremost centre for astronomical work, 'the Greenwich of Indian astronomy and the Arin of the Arabic and Latin astronomical treatises.' Here in A.D. 150, Pingree informs us, Yavaneśvara, the Lord of the Greeks, translated into Sanskrit prose a Greek astrological text which had been written in Alexandria the preceeding half century.[106] This translation is not extant, but its subject matter has survived in the form of a thirteenth century palm-leaf manuscript of a versification of it carried out by Yavanarāja Sphujidhvaja in A.D. 269/270 to which a reference has just been made. In the second century A.D. another astrological text of the same type was translated into Sanskrit from a Greek original; this translation has not survived. This is known through references of Yavanarāja and Satya who utilized both the translations.

In his 'Astronomy and Astrology in India and Iran', Pingree conjectured that the concept of great cycles of time,—the *Kalpa, Mahāyuga, Yuga* etc., in which the planets and some of their nodes and apses underwent integral numbers of revolutions according to Hindu astronomy, was derived from the Babylonian sexagesimal number 2, 0, 0, 0.[107] Written decimally, this number is equivalent to 432,000 used for the *Kaliyuga;* 10 times the *Kaliyuga* is the *Mahāyuga,* and 1000 times the *Mahāyuga* the *Kalpa.* He further conjectured that this *Kalpa* of Babylonian origin was combined with the Greek epicyclic theory during the 4th or the 5th century A.D. Apart from the sub-divisions of the *Mahāyuga* in the ratios 4:3, 3:2, and 2:1, a small period of 180,000 years being 124th part of a *Mahāyuga* was tried, but without much success. In A.D. 499, Āryabhaṭa tried to solve the problem by dividing the *Mahāyuga* in four equal parts of 1,080,000 years each, but could not make it acceptable to others because of its deviation from the tradition. Pingree thinks that the Indian *yuga* system finally took shape in the Gupta period and was the result of 'the necessary theoretical knowledge and the inspiration'.

Being thus convinced of the influence of Babylonian and Greek astronomical elements Pingree's subsequent efforts were directed to explain various facts of Indian astronomy in the light of his theory of transmission. That Indian epicyclic models were inspired by the older Greek ones of Apollonius of Perga and Hipparchus has long been suspected. Pingree now attempted to show that the earliest specimen of this model, the double epicycle, appeared in the *Paitāmaha-siddhānta* of the *Viṣṇu-dharmottarapurāṇa* which he placed in the first half of the fifth century A.D. and supposed to be the source of Āryabhaṭa's system.[108] The dating and assertions are speculative and have been questioned by B. L. van der Waerden. Precession and trepidation of equinoxes have been traced in Indian astronomy in the *Jyotiṣa-vedāṅga* of Lagadha, Varāhamihira's *Pañcasiddhāntikā,* and in later astronomical siddhāntas. The appearance of these ideas in Greek literature before they did in the Sanskrit and references to one Maṇindha or Maṇittha (Gk. Manethon) led him to conjecture, even with regard to the earliest notions preserved in the *Jyotiṣa,* that 'it is not unreasonable to suppose that the *idea* of trepidation or precession was introduced into India by the Greeks, though the *parameters* chosen by the Indians are their own, and that the arguments presented in favour of the hypothesis of a motion of the colures are derived from a particular interpretation of the *Vedāṅga jyotiṣa*'.[109]

In a number of areas such as the later *Pauliśa-siddhānta,* al-Fazārī, Ya'qūb ibn Ṭāriq and several others our information has so far been fragmentary and based on the repetition of a certain tradition. In some of these Pingree collected all the traceable fragments, explained them in the form of commentaries, and critically examined some of the traditions. The later *Pauliśa-siddhānta* which al-Bīrūnī used with the help of his Pandit was compiled in Western or North-Western India, probably at Sthāniśvara, between c. A.D. 700 and 800. Besides al-Bīrūnī's Pandit, the work was known to and quoted from by Pṛthūdakasvāmin, Utpala and Āmarāja. Pingree collected all these citations in a total of 37 verses as also Bīrūnī's references, explained their astronomical elements and showed that this later *Pauliśa-siddhānta* was based on Āryabhaṭa's *ārdharātrika* system.[110] In its popularity the work rivalled that of *Khaṇḍakhādyaka,* and fell into disuse after the thirteenth century. Astronomer Muḥammad ibn Ibrāhīm al-Fazārī's fragments have been collected from Ibn al-Adamī's *Naẓm al-'Iqd,* Ṣā'id al-Andalusī's *Kitāb ṭabaqāt al-umam* al-Hāshimī's *Kitāb 'ilal al-zizāt,* Bīrūnī's *India, Chronology, al-Qānūn al-Mas'ūdī* and other tracts, al-Hamdānī's *Sifat Jazīrat al-'Arab,* and a few others. Pingree has shown that the Sanskrit works in 12(?) chapters translated into Arabic was probably based on a work entitled *Mahāsiddhānta,* which was itself based on Brahmagupta's *Brāhmasphuṭa-siddhānta* with certain modifications.[111] Ya'qūb ibn Ṭāriq's fragments have been dealt with in the same manner, his principal sources being al-Hāshimī's *Kitāb,* al-Bīrūnī's *India* and other works, Abraham ben Ezra's preface to his translation of ibn al-Muthannā's *Fi 'ilal zij al-Khwārizmī*[112]

Pingree has also carried out a useful survey of Sanskrit astronomical tables in the United States, and contributed several biographical notes to the *Dictionary of Scientific Biography,* including an article on the history of mathematical astronomy in India.

VAN DER WAERDEN ON TAMIL, AND OTHER PROBLEMS OF HINDU ASTRONOMY

Shortly after the appearance in the *Orisis* of Neugebauer's study of Tamil astronomy Bartel L. van der Waerden of Zürich carried out a comparative study of the motion of the Sun as per Greek astrological tables and the Indian tables compiled by Le Gentil and Warren. In Hellenistic times the Greek astrological tables used to be constructed according to two methods, namely, the Babylonian linear method and the Alexandrian trigonometrical method. Although called Babylonian, the method of linear interpolation between extreme values involving the use of arithmetical series with first, second or third order was not limited to Babylon alone but was used by the astronomers and astrologers in Alexandria and Rome as well.[113] The Alexandrian method due to Aristarchus, Apollonius, Hipparchus and Ptolemy involved the application of geometrical models (circle, excentre and epicycle) to planetary motions and the use of trigonometrical tables. In Indian astronomy, as Thibaut had already recognized, the linear method was the characteristic of its middle period and the trigonometric one that of its third period.

With regard to the motion of the Sun as implied in the tables of Le Gentil and Warren, van der Waerden showed that a geometric model of a concentre with an equant point was used. The distance of the equant point from the centre was computed as 0; 2, 15, 19 and the direction of the equant point (the longitude of the apogee) as 78°. The concentre model (Fig. 3·4) leads to the following simple formula for the equation of centre ω :

$$\sin \omega = \frac{r \sin u}{R}$$

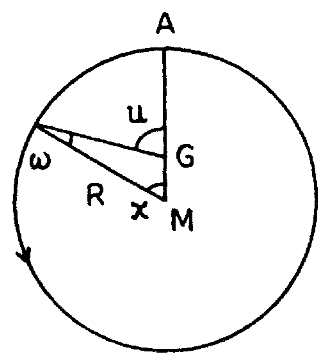


Fig. 3.4. Concentre with on equant point

Such a model was used by Eudoxus and Kallippus. Next he showed that the epicyclic theory of Āryabhaṭa and *Sūrya-siddhānta,* with the approximate value of radius also produced the same formula. Moreover, Āryabhaṭa's eccentricity (r/R) : $13\frac{1}{2}/360 =$ $.0375 =$ 0; 2, 15 compared favourably with the value of 0; 2, 15, 19 obtained by Fourier analysis of the Tamil table. For the longitude of the apogee the Tamil table also used Āryabhaṭa's value of 78°.

With regard to the calculation of eclipses, the Tamil tables used four periods which Neugebauer designated by V, R, C and D. Van der Waerden showed that the period V comprising 1600984 days was not a lunar period but the *ahargaṇa*, that is, the number of days elasped from the beginning of the Kaliyuga upto May 22, 1282, at which date the Moon was in its apogee. "The whole Vākyam process," van der Waerden observed, "can be applied only to dates after May 22, 1282. For that date the computed longitude and latitude are very accurate. The Vākyam method cannot have obtained its present form before that date."[114]

Van der Waerden also analyzed the lunar latitude tables given by Le Gentil and found that the approximate trigonometrical relation $\beta = B \sin u$ (correct formula, $\sin \beta = \sin B \sin u$) was used in their compilation. Trigonometrical formula characteristic of astronomical *siddhāntas* were again the basis of computation of right and oblique ascensions tables.

Thus, the Vākyam process and other astronomical relations employed in the Tamil computation of eclipses were characteristic of Thibaut's third period of Indian astronomy when trigonometrical methods were the dominant features. In the light of this analysis the conjuncture of the transmission of Tamil countries of Babylonian linear methods in the course of Indo-Roman trade during the first few centuries of the Christian era appear highly improbable.

Motion of Venus. Following the translation by Neugebauer and Pingree of the the *Pañcasiddhāntikā*, P. B. Wirth reconsidered Vasiṣṭha's Venus theory as given in the first five verses of the last chapter (ch. XVII in NP edition and ch. XVIII in TS edition), questioned the editor's emendation of the original term '*guṇāptaiḥ*' to '*guṇāṃśāḥ*' ("and $\frac{1}{2}$ (degrees)), and showed that an astronomically acceptable explanation of the velocity scheme presented in these verses did not call for such emendation.[115] Unable to refute Wirth's astronomical interpretation Pingree critized him fron linguistic point of view. Van der Waerden clarified the controversy by justifying Wirth's astronomical interpretation with reference to Egyptian planetary theory as found in 'Stobart Tables' and providing a linguistic explanation by Dr. A. Bloch, Professor of Sanskrit at the University of Basel.[116] Waerden demonstrated that if the unintelligible word '*guṇāpataiḥ*' be ignored, XVII. 1 of the *Pañc.* would simply mean, 'The progress in longitude of Venus in one synodic period is $215\frac{1}{2}$ degrees.' In a subsequent verse XVII. 75, Varāha correctly gave the equivalence between revolutions and synodic periods for Venus as 1151 revolutions equalling 720 synodic periods, which meant that in one synodic period Venus moved through $1151.360°/720$ or $360+215\frac{1}{2}$ degrees, that is, the planet's longitude was $215\frac{1}{2}°$. In a like manner van der Waerden explained the direct and retrograde motions of Venus and demonstrated their perfect agreement with Egyptian planetary tables. As to the linguistic interpretation, Bloch stated as follows, 'From a linguistic point of view I still consider Pingree's interpretation"..guṇāṃśāḥ, which I take to be bahuvrīhi compound modifying pañca (aṃśāḥ) and meaning "with $\frac{1}{2}$ (of a degree)" ((3), 37)" as highly improbable..'[117]

Origin of Great Cycles and Hindu Astronomical Yugas

Hindu astronomical *siddhāntas* of the period from A.D. 500 to modern times are based on two fundamental assumptions, e.g. (1) a yuga or a certain large period of time at the beginning and end of which all planets have the same mean longitudes, and (2) the beginning of a period in between 17 and 18 February, 3102 B.C., called the Kaliyuga era, was such that at this date the mean longitudes of planets with respect to Aries were zero. The first fundamental period, the *Mahāyuga* of 4,320,000 years was adopted by Āryabhaṭa and his followers in the beginning of the sixth century A.D. while Brahmagupta and others preferred *Kalpa* of 1000 *Mahāyugas*. Regarding the beginning of the *Kaliyuga* at the instant of conjunction of planets, Āryabhaṭa worked on two reckonings, namely, (1) that the conjunction took place in the midnight between February 17 and 18, and (2) that it happened at the sunrise of February 18; the *ārdharātrika* system was based on the first assumption and the *audayika* on the second. The advantage of developing a system on these two assumptions is that necessary corrections can be introduced by making one single observation for each planet as Āryabhaṭa did in the case of Jupiter by changing its revolution number in a *Mahāyuga* from 364, 220 in his mid-night system to 364, 224 in the sun-rise system (this meant an increase is mean longitude of Jupiter by 1°12').[118] The method was much simpler than Ptolemy's. The disadvantage is that as time goes on it does not yield mean motions of planets correctly and necessitates *bīja* corrections to be applied from time to time.

Van der Waerden investigated the question of the origin of great years in Greek, Persian, and Indian astronomy in a number of papers, and gave a final shape to his findings in a paper in the *Archive for History of Exact Sciences* (**18**, 359-384, 1978).[119] The idea of 'the eternal return of all things' at the end of a long enough period of time and of such cycles being marked by conflagration or great natural calamities have been traced to early Greek philosophers like the Pythagoreans, Namesios, and Stoic philosophers. The concept of a Great Year associated with flood and planetary conjunctions probably originated with the Babylonians, in which connection the name of Berossos, a priest of the Babylonian god of BEL is specially mentioned. He foretold that there would be a conflagration when all planets had a conjunction in Cancer and a deluge when they all met in Capricorn. He further estimated that before the Flood the sum or regnal years of mythical kings totalled 120 *saroi* or 432000 years (1 *sar* = 3600 years). In his chronological system Berossos also used other units such as

saros = 3600 years
neros = 360 years
sossos = 60 years

from which also the great year of 432000 could be obtained as 120 saroi or 1200 neroi.

As to great years mentioned in later Greek literature, van der Waerden refers to the Great Year of Orpheus comprising 120000 years, and Cassandrus' of 3600000 years. All these years are built out of factors 120 and 3600 which Berossos used in estimating the sum of regnal years before the Flood.

In India a *yuga* system is met with in the Laws of Manu and the *Mahābhārata*. The epic discusses the division of time, defines larger units like the 'year of the gods' (= 360 ordinary years), and introduces the four mundane ages, e.g. *Krita, Tretā, Dvāpara* and *Kali* with the following lengths of time :

Kritayuga	= 4800 years of the gods	=	1,728,000	years
Tretāyuga	= 3600 ,, ,, ,,	=	1,296,000	,,
Dvāparayuga	= 2400 ,, ,, ,,	=	864,000	,,
Kaliyuga	= 1200 ,, ,, ,,	=	432,000	,,

Van der Waerden thinks that the Hindu year of the gods is the Babylonian neros, from which were derived the *Kaliyuga* by using the factor 1200 and the *Mahāyuga* by using another factor 12000.[120] Pingree, as we have seen, made a similar statement with reference to the Babylonian sexagesimal number 2, 0, 0, 0. Although the Babylonian connection is easy to infer it is more difficult to demonstrate the channels of transmission. The problem is complicated by the use of long periods or world-years in old Persian calendars and various statements of Arab astrologers-cum-astronomers suggesting Babylonian and Hellenistic transmission in Persia. Then there is the problem of who first demonstrated the possibility of planetary conjunctions in February 3102 B.C., and how and where it was done.

Three world-years are recognized in the works of Abū Ma'shar and al-Sijzī, as follows :—

(1) a World-Year of 4,320,000,000 years, ascribed to India;
(2) a World-Year of 4,320,000 years ascribed to *Aryabhaz* (Āryabhaṭa); and
(3) a World-Year of 360,000 years ascribed in some works to 'The Persians' and in others to 'the Persians and some of the Babylonians'.

While the first two world-years pose no problem and have been correctly attributed to Indian sources, the third world-year sometimes called 'Abū Ma'shar's Great Year' required a closer scrutiny. Van der Waerden drew upon al-Bīrūnī's evidence in his *Chronology* to show that Abū Ma'shar's source for his Great Year of 360,000 years was the Tables of the Shāh and that the planetary revolution numbers in this period quoted by al-Bīrūnī were taken from Persian sources. Waerden converted Āryabhaṭa's revolution numbers for his two systems for Abū Ma'shar's period and found exact agreement with the exception of Saturn, Jupiter and Mercury. Moreover, all the three systems agreed in the theory of planetary conjunctions at the first point *O* of Aries in February 3102 B.C., with the difference that the conjunction was attended with a Flood and it took place on the night just before Thursday, February 17.[121]

This brings us to the question of the Tables of the Shāh. The Arabic title of these tables is the *Zīj ash-Shāh* which in turn represented a translation of the Pahlavi original, the *Zīk-i-Shatroayār*. From Bīrūnī's statement in the Masudic canon it is known that Khurso Anūshīrvān (ruled from A.D. 531 to A.D. 579) held a conference of astronomers to revise the *Zīj ash-Shahriyār*. Van der Waerden has shown that Ibn

Yūnis in his *Hākimi Zij* clearly mentions that the solar apogee of the Sun was observed by the Persians in A.D. 450 and again in A.D. 610; the former observation yielded 77°55' and the latter 80°. These references imply, according to Waerden, that 'a set of astronomical tables was composed about 450 or a little later, and revised under Khusro Anūshīrvān about 560.'[122] In other words, by the middle of the fifth century A.D. Sassanian Persia had developed sufficient capability so as to undertake the compilation of astronomical tables. From the *Dênkart* we know of Shāpūr I's (A.D. 240-270) interest in astronomy and the availability to Persian scholars of Ptolemy's *Almagest,* astrologer Dorotheos' hexameters and Vettius Valens' 'Anthologies'. By the time of solar apogee observations, the Persians had probably mastered the methods of computing mean conjunctions of Jupiter and Saturn and known the time interval between two successive conjunctions of Jupiter and Saturn as 20 years approximately. Waerden has shown that all this could be possible if the Persians of the fifth century A.D. had possessed a great cycle of 360,000 years in which Jupiter and Saturn revolved 30352 and 12214 times respectively and therefore suffered 18138 mean conjunctions.[123]

Now about the conjunction of planets in the month of February in the year 3102 B.C., it is easy to make sure that no such observation could have been made. In P. V. Neugebauer's *Chronological Tables* for 3102 B.C., longitudes of planets on February 18 noon were calculated as follows :—Sun—304; Moon—324 = 304+20; Mercury—289 = 304—15; Venus—318 = 304+14; Mars—302 = 304—2; Jupiter—318 = 304+14; and Saturn—277 = 304—27. The angular distance between Jupiter and Saturn alone exceeded 40°. As to records of earliest astronomical observations there are those of the visibility of Venus taken during the reign of Ammizaduga (*c.* 1582—1562 B.C.) and a few cuneiform texts from the time of Nabonassar (after 750 B.C.). The only other possibility was to compute the conjunctions backward.

According to van der Waerden, Sanskrit astronomical works do not suggest such backward computation, but Persian sources as preserved in the writings of later Arab astronomers do. In any such procedure one would obviously have to start with the slowest planets Saturn and Jupiter (in the case of the Sun and the Moon a conjunction takes place very month). In his *Book of Conjunctions,* Abū Ma'shar used Persian sources for mean motions of these two planets and showed that 18,138 mean conjunctions took place in 360,000 years, that is, one conjunction is nearly 20 years, and the mean motion from one conjunction to the next was 242°25'17" (=8 signs + 2°25'17" through the simplification of $\frac{12{,}214 \times 360°}{18{,}138}$.[124]

A Saturn-Jupiter conjunction at intervals of nearly 20 years is a 'small conjunction'. If one starts with such a conjunction in the beginning of Aries, the next two will occur in Sagittarius and Leo, and these three signs constitute 'Fire Triplicity'. After about 12 conjunctions in the 'Fire Triplicity', another series will connect the three signs of Taurus, Capricorn and Virgo and form the 'Earth Triplicity', the shift being due to a slow gain in longitude. Likewise, the 'Air Triplicity' comprising the

signs Gemini, Aquarius and Libra, and the 'Water Triplicity' through Cancer, Pisces and Scorpio (Fig. 3.5). Twelve conjunctions in one and the same triplicity, van der Waerden explains, constitute a 'Middle Conjunction', four Middle Conjunctions covering all triplicities make up a 'Big Conjunction', and three Big Conjunctions constitute a 'Mighty conjunction', after which the cycle repeats itself.[125] On the basis of such Saturn-Jupiter conjunctions, their triplicities and cycles, one can develop long periods.

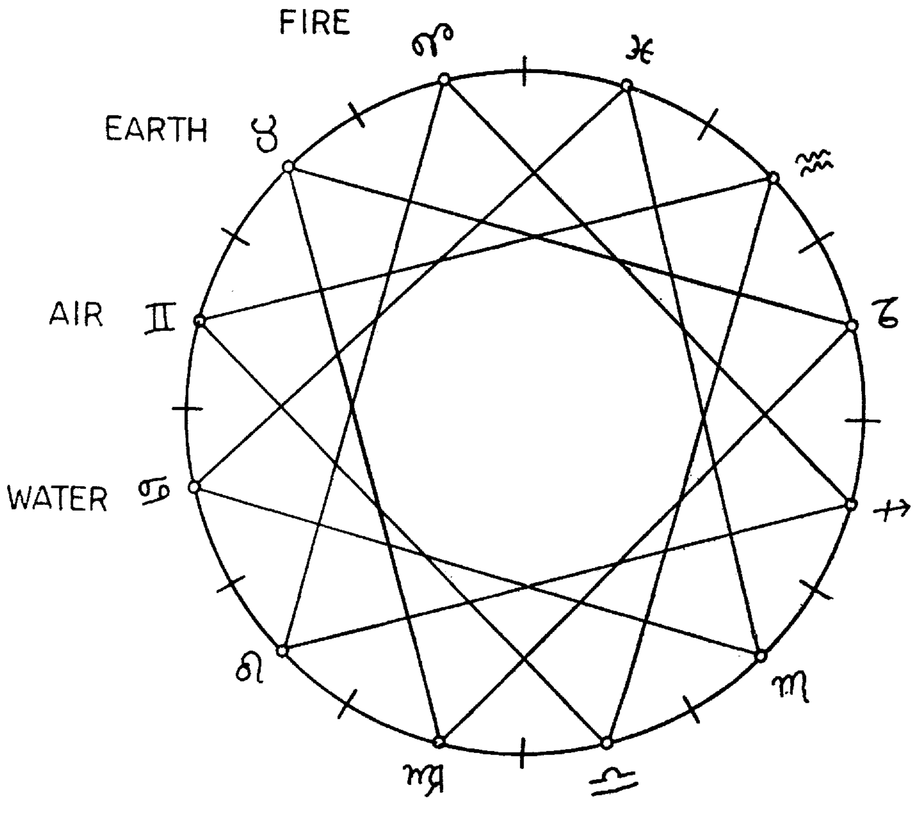


Fig. 3.5. Triplicities in Saturn-Jupiter Conjunctions.

The conjunction of 3102 B.C. taking place at the beginning of Aries was regarded as a Mighty Conjunction. Māshāllāh and other Arab astrologers who derived the method from the Persians are known to have carried out several calculations of this type to obtain long periods.

Al-Bīrūnī records in his *Chronology* that the astrologers of Babel and Chaldaea constructed astronomical tables for dating the Deluge, which Berossos had associated with Saturn-Jupiter conjunctions. "Now this conjunction occurred 229 years 108 days before the Deluge. This date they studied carefully, and tried by that to correct the subsequent times. So they found as the interval between the Deluge and the

beginning of the reign of the first Nebukadnezar 2,604 years,. ." (Bīrūnī, *Chronology*, p. 28). Van der Waerden explains that if 2604 years be added to the "Era of Nabonassar" beginning on February 26, 747 B.C., as per Ptolemy, one obtains 3351 B.C. as the year of the Flood on Julian year-reckoning. The Saturn-Jupiter conjunction took place 229 years (neglecting the number of days) before that date, that is, in 3580 B.C. This year differs from 3102 B.C. by 478 years, which just accommodate 24 successive mean conjunctions of Saturn and Jupiter.[126] Other astrologers dated the Deluge differently. One such date was 3301 B.C., and counting ten such conjunctions one could arrive at 3102 B.C. But it is still hypothetical. From Bīrūnī's account of the search for a date of the Flood when all the planets were in conjunction, it appears that Abū Ma'shar Albalkhī gave this date as 3102 B.C. February 17.

The next question is: who were the astrologers of Babel and Chaldaea ? Van der Waerden thinks they could not be early Babylonians conversant with systems A and B because 'mean longitudes' were not known to them. Necessity for working with mean longitudes arose only after the development of epicyclic geometric models. Planetary tables based on epicyclic models were not available before 150 B.C.; therefore, it is surmised that 'the discovery of the conjunction of 3102 can be dated, with a certain degree of probability, between −150 and +150.' This was again the period which witnessed the spread of Hellenistic astronomy over a wide region, —Rome, Alexandria, Pergamon, Babylon etc. A number of Babylonian astronomers or astrologers such as "Teukros the Babylonian', 'Seleukos of Seleukia' versed in Greek astronomical methods are known from this period. In this Hellenistic milieu, van der Waerden conjunctures, the conjunctions of 3102 B.C. was discovered somewhere between Rome and Babylon.

Closely connected with the epoch of 3102 B.C. is the duration of the sidereal year. According to al-Bīrūnī, Egyptians and the Babylonians used a sidereal year of 365; 15, 30, which appeared in Varāhamihira's *Pauliśa-siddhānta*. The *Shāh Zij* gave the value of 365; 15, 30, 0, 30 days. Āryabhaṭa, in his mid-night system, used the value of 365, 15, 31, 30 and, in his sun-rise system, that of 365; 15, 32, 30. The transmission also took place in the same order of evaluation of the constant of sidereal year length. "The starting point of the whole development," concludes van der Waerden, "was the 'Mature Epicycle Theory' of Apollonius. Based on this theory and on trigonometrical methods, tables were calculated for the longitude of Alexandria. By the aid of these tables, several Hellenistic astrologers tried to date the Deluge by calculating conjunctions of Jupiter and Saturn in the fourth millennium B.C. One of these attempts led to the discovery of an approximate mean conjunction of all planets in 3102 B.C. Next, a new theory and new tables were fabricated, based on the assumption of a mean conjunction of all planets in February, 3102, and of an exact repetition of all planetary positions at the end of a certain "World-Year". These tables were used, with corrections, in Sassanid Persia before and after Khusto Anushīrvān. Āryabhaṭa corrected the theory, replacing the Persian World-Year of 360,000 years by a period twelve times as large, the Mahāyuga, which enabled him to adopt the theory to observations made in his own time, Other Hindu astronomers like

Brahmagupta, used the *Kalpa* of 1,000 *Mahāyugas* in order to obtain theories in which the mean longitudes, apogees and nodes of all planets were assumed to be zero at the beginning of the *Kalpa.*[127]

ROGER BILLARD'S L'ASTRONOMIE INDIENNE

In 1971 Roger Billard published his *L'Astronomie indienne investigation des textes Sanskrits et des donnés numeriques* (Indian Astronomy,—an investigation of Sanskrit texts and their numerical data). In this investigation the author adopted the novel procedure of mathematical statistics, based in particular on the method of least squares, analyzed a large number of astronomical *siddhāntas,* and graphically represented the deviations (écarts) against time of longitudes calculated according to the texts from those obtained from modern procedures and tables. From these deviation curves he determined independently and with accuracy the dates of compositions of a number of texts. Furthermore, it was established that exact agreement between actual positions of planets and those calculated theoretically from the constants and formulae of their cannons was secured from time to time by astronomical observations quite accurate for the ancient times under consideration.

Billard recognized three periods in the development of Indian astronomy. The first period dated from the time of the Brāhmaṇas (10th—8th century B.C.) and extended up to the 3rd century B.C.; its characteristic feature was calendrical astronomy and the representative text the *Jyotiṣavedāṅga.* The second period extended from the 3rd century B.C. to the 1st century A.D. and was marked by Babylonian astronomical elements, particularly the *tithi* as a unit of time, arithmetical computations based on heliacal risings and settings of planets, their synodic revolutions etc. The third period,—the period of scientific astronomy, extended from around A.D. 400 up to modern times, was characterized by the employment of trigonometrical methods and epicyclic models for the computations of planetary positions, and produced the *Āryabhaṭīya* of Āryabhaṭa as its first typical text. Billard's main concern was with this scientific astronomy of the third period because the relevant texts and materials readily lent themselves to investigation by the statistical method he adopted.[128]

With the exception of a few texts anterior to A.D. 500, and manifestly imported, the astronomical works of this period are marked by a fantastic speculation, that of the imaginary *yuga,* in which are fitted the mean motions of planets in the form of integral numbers of revolutions and their conjunctions, and various other methods for the calculations of true positions with the help of trigonometry. In all appearances, it was, according to Billard, Āryabhaṭa who in the beginning of the sixth century A.D. was the first astronomer to have laden the scientific trigonometric astronomy with the bewildering speculation of the *yuga.* Yet this speculation was not entirely unbriddled, for it was checked and tested from time to time by a series of astronomical observations and reductions, which constituted the limits of ancient astronomical methods. Sanskrit astronomical texts themselves speak of these observa-

tions when these use terms like *dṛkprabhāvāt* (by the imposition of observation), *dṛksama* (in response to observation), *dṛṣṭigaṇitaikya* (accord between observation and calculation), and *dṛggaṇitakāraka* (that which establishes an accord between observation and calculation). Thus Āryabhaṭa was possibly moved by the idea of a Great Year of Berossos which could be suggested to him verbally; thereupon he sought for the constants of mean motions to construct the common multiples and the general conjunctions in accordance with his practical observation in A.D. 510 or very near that date.[129]

In chapter 2 of his *l'Astronomie,* Billard has given an adequate exposition of his statistical method of testing ancient astronomical texts. The first consideration is the choice of a suitable ancient element which has also its equivalent in modern computations. Such an element is the mean longitude ,$\mathcal{L}$ a linear function of time in the form

$$\mathcal{L}(t) = \mathcal{L}_o + ct.$$

For the Sun, Moon and the five planets Mercury, Venus, Mars, Jupiter and Saturn, seven mean longitudes have to be taken into account; along with these seven elements, one should also consider the vernal equinox ♈, and the apside and node of the Moon. The same ten functions can be computed from modern theory and compared with the value obtained from ancient theories. The deviations between these two sets of values have been called 'écarts'. Billard computed two types of deviations, e.g. those of mean longitudes as defined by the above formula, and synodic deviations, the latter to be derived by combining with the longitudes of the Sun (formula is given on p. 48).

Before applying the method of Sanskrit astronomical canons, Billard first tested its reliability with respect to Ptolemy's *Almagest (Mathematical Syntaxis)*. Billard calls the *Almagest* a non-speculative treatise inasmuch as its elements were based on contemporary as well as ancient observations and consequently the mean motions of planets were precise. The epoch of the *Almagest* was taken to be February 26, A.D. 746 Julian. Between this date and February 2, A.D. 141 Julian there were records of 76 observations, mostly of lunar eclipses and a few of planets. These observations included several Babylonian records of lunar eclipses taken before A.D. 381 Julian, observations by Timocharis at Alexandria, about 10 observations utilized by Hipparchus, and about 33 observations by Ptolemy himself. Ptolemy's constants, —apogees, eccentricities, and radii of epicycles, and formulae for converting mean longitudes into true ones have also been given. Deviations of longitudes and synodics have been represented graphically against time - 500 to + 1900 (Billard's figs. 1 & 2). With the exception of Mercury and Venus, longitude deviation curves, mostly straight lines (sinusoidal for Jupiter and Saturn), lie in a narrow bundle converging to a point corresponding to A.D. 100, approximately the time of Ptolemy. The error of nearly 1° is also in keeping with Ptolemy's observational error. The year of no error, that is, —125 A.D. agrees with Hipparchus' time.[130]

The results of Billard's statistical analyses of Āryabhaṭa's two systems, the *ārdharātrika* and the *audavika,* are discussed in chapter IV. In the former the epoch is the mid-night at the beginning of the *Kaliyuga,* and the *yuga* comprises 4,320,000

years or 1577917800 civil days, while in the latter the *Kaliyuga* starts at the following sun-rise and the *yuga* is made to contain 1577917500 days. This adjustment of 300 days will be understood when one computes the number of days elapsed in 3600 years of the *Kaliyuga* era on Sunday March 21, A.D. 499 Julian 12 hour at the meridian on Ujjayinī. The days are 1314931.5 (mid-night system) and 1314931.25 (sun-rise system) satisfying the following relationship;[131]

$$\frac{1314931.5}{1577917800} = \frac{1314931.25}{1577917500} = \frac{3600}{4320000} = \frac{1}{1200}$$

The number of revolutions of the planets in a *yuga,* the longitudes of their *manda* apses, and the dimensions of their *manda* and *śighra* epicycles are then tabulated, giving details of the variability of the epicycles in the sun-rise system. Formulae for computing equations of centre and conjunction are also given. With these elements the deviations of longitudes and synodics were electronically computed for the two systems and the desired graphics for écarts against time (-500 to $+1900$) obtained. Unlike the *Almagest,* the lines of the graphics in both the Āryabhaṭa systems form a pencil spreading out rapidly from the zone of coincidence. In both cases the zone of coincidence, which is sufficiently sharp, meets the line of zero deviation shortly after A.D. 500 (around A.D. 510). In both systems the curve for Mercury is wide of the mark, but that for Jupiter which is out of step in the mid-night system aligns itself with the majority of the pencil converging on the common zone of null deviation around A.D. 510. Billard interprets these results as showing that the mid-night system was the earlier of the two canons and that, as a result of observations carried out around A.D. 510, the more accurate sun-rise system was developed by slightly changing the revolution number of Jupiter in the *yuga* and by making the dimensions of the epicycles variable. The very nature of distortion or spread away from the zone of coincidence provides a powerful tool for pin-pointing the time of emendation through observation. In Billard's own words: "Il vient tout d'abord l'importante constatation generale: ces elements astronomiques dont on verra plus encore (4, 3, 5) la caractere fantastique, reposent malgre tout sur des observations astronomiques, un ensemble unique d'observations tres rapprochees dans le temps et necessairement de tres grande qualite pour les moyens de l'epoque."[132] The same conclusion is true for other speculative astronomical *siddhāntas* produced in India. Billard was convinced not only of the fact of astronomical observations made in India from time to time, but was struck by their precision which represented the limit of accuracy attainable by the ancient instruments and methods of observation. Thus about Āryabhaṭa he unhesitatingly observed: "On ne manquera pas de remarquer l'etonnante precision de ces ensembles de position pendant la periode des observations: Cette precision etait certainement a la limite des moyens de l'astronomie ancienne, a la limite de ses instruments et de ses modeles mathematiques. C'est dire des a present qu'en depit de la speculation yuga, Aryabhata est certainement l'une des grandes figures de l'histoire de l'astronomie."[133] This view is in marked contrast to the opinions expressed by Colebrooke, Biot, Kaye and others that ancient Indians were poor in astronomical observations.

Space would not permit consideration of Billard's results for his analyses of various other texts, but a few typical results might be mentioned. It is interesting to see that in cases where the date of the text is known, his statistical dating agrees with the known date. This strengthens the reliability of his method in cases where the dating is either unknown or doubtful.

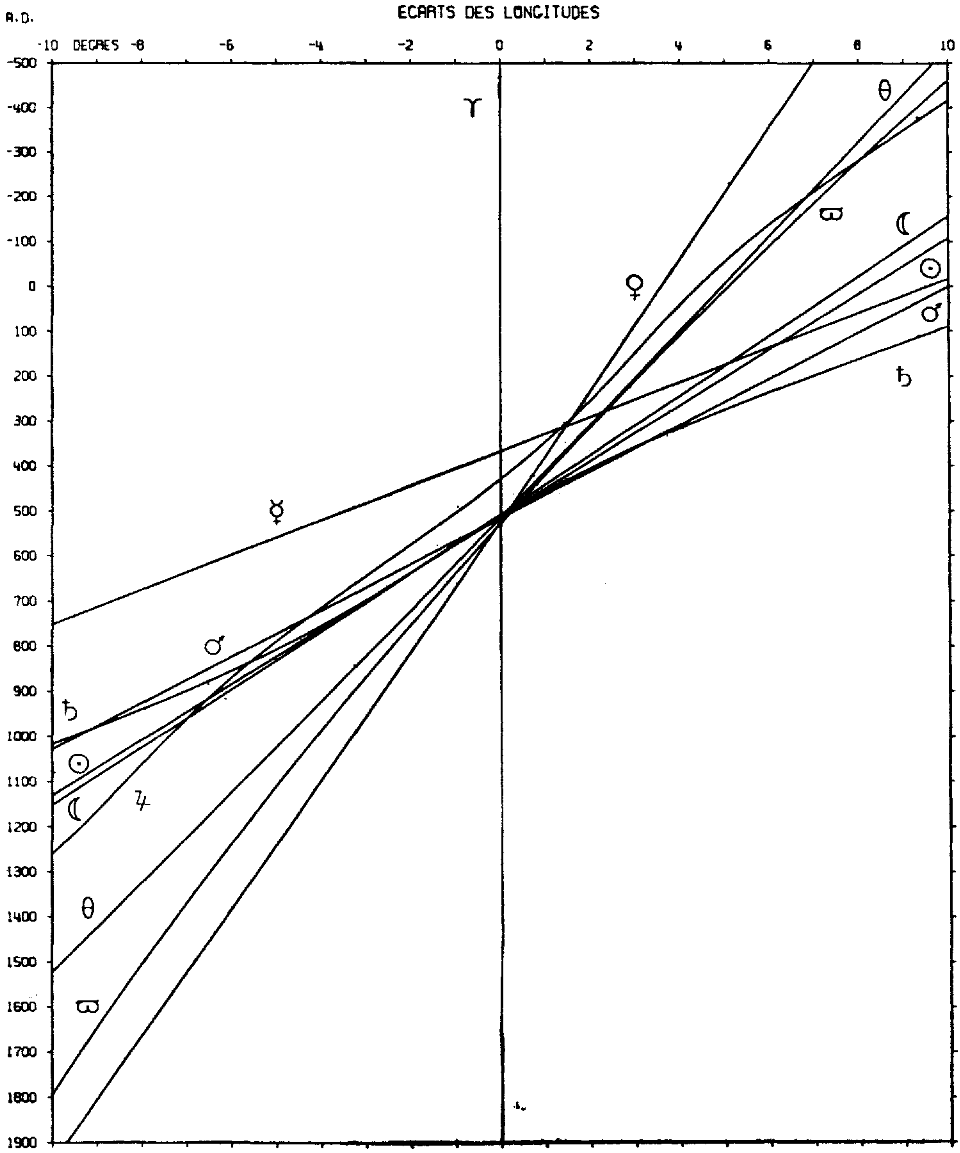


Fig. 3.6. Deviations of longitudes, K. *(S.S.)* *(ārdharātrika)* (from Billard, Fig. 3)

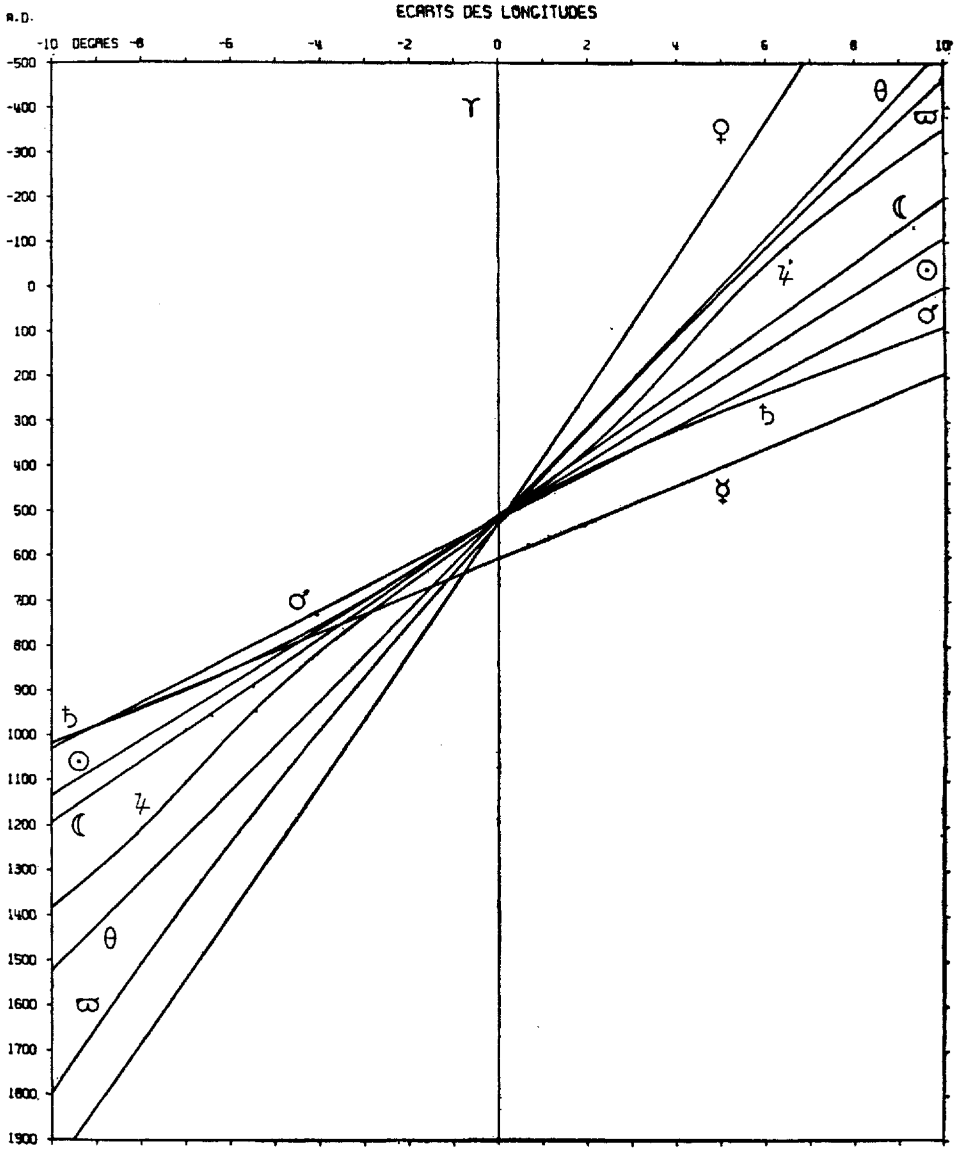


Fig. 3.7. Deviations of longitudes, K. *AB (audayika)* (from Billard, Fig. 5)

Text	*Textual evidence*	*Billard's statistical Method*	*Remarks*
Pañc. S	c. A.D. 505	490.3±6,8 to 512.1±3.6	
Brāhmasphuṭa-siddhānta	A.D. 628	555.2±14.3 to 586.5±18.0	Planetary observations anti-date the composition of the text.
Khaṇḍakhādyaka	A.D. 665	680.7±(12.3) to 729.8±9.6	
do (Āmarāja)	,,	694.5 (8.4) to 739.9±(19.5)	The work appears to have been completed or recast well after 665, possibly at the beginning of the 8th century A.D.
Laghubhāskariya by Śaṅkaranārnāyaṇa	A.D. 869	785.9±13.6 to 822.6±(0.5)	The canon could possibly be dated between A.D. 807 and 821.
Dṛggaṇita of Parameśvara	A.D. 1431	1427.2±17.0 to 1475.6±15.1	carried out a large number of observations, particularly of the eclipses.

What is refreshingly new in Billard's study is his endeavour, with the help of modern statistical-cum-computer methods, to understand the true nature, the merit, the originality and the shortcomings of an astronomical system which functioned as an active and effective institution for over fourteen centuries and maintained its vitality through periodical observations, and emendations. The work is a strange contrast to the general efforts of Western scholars directed at digging evidence in favour of their theory of the imported character of the system, its lack of originality, its absence of an observational basis and so on.

David Pingree came forward with a scathing criticism of Billard's *l'Astronomie* (*JRAS,* 1976) presumably because some of his own conclusions were diametrically opposed to those of Billard's. In 1978 he also presented the results of his studies in an article entitled 'History of Mathematical Astronomy in India' in the *Dictionary of Scientific Biography* (vol. XV, Supplement I, 1978). The views presented in Billard's *l'Astronomie,* and Pingree's *Mathematical Astronomy* are so opposed to each other's that both cannot be simultaneously right, and therefore one of them must be wrong. This peculiar situation led van der Waerden to publish in 1980 in the *Journal for the History of Astronomy* a critical review of both these treatises, which deserves close consideration.

Pingree objected to Billard's graphic demonstration that Āryabhata improved upon his earlier mid-night system by utilizing his observations made in A.D. 510. According to Pingree, Āryabhaṭa's mean motions 'apparently are computed from

the assumed mean conjunction of the beginning of the Kaliyuga and the mean longitudes of the planets as found from a Greek table for exactly 3600 years later—that is, for noon of 21 March 499." Further more, "..Āryabhaṭa could only observe true, not mean longitudes. It is not an easy matter to deduce the mean longitudes from these true longitudes, and for Āryabhaṭa, with his rather clumsy and inaccurate planetary models, it would have been impossible to arrive at results as good as Billard shows his to be." On Pingree's theory of Āryabhaṭa's dependence on Greek planetary tables, van der Waerden considers it practically impossible for the following reason: "The most accurate Greek tables were the *Handy Tables* of Ptolemy: They were used in Alexandria and Byzantium in the time between Ptolemy and Āryabhaṭa. As far as longitudes are concerned, these tables are based on the *Almagest*. Now leaving aside the very difficult planet Mercury, the deviations of Ptolemy's mean longitudes in A.D. 510 are (in degrees according to Billard's calculations): Equinox—0 (by definition); Sun—2.7; Moon —2.6; Moon's node—3.1; Moon's apogee—3.0; Venus—5.2; Mars—2.6; Jupiter—1.6; Saturn—3.0. Without any doubt, pre-Ptolemaic Greek tables would give rise to still larger deviations. Usually, the errors of astronomical tables tend to increase in the course of time. By sheer accident, it may happen that for one or two planets the deviations become nearly zero for a particular year, but in Figure 5 we have nine deviations which simultaneously become extremely small in A.D. 510. The only possible explanation is that the mean longitudes were determined by accurate observations around A.D. 510."[134]

As to Pingree's other contention that Āryabhaṭa could observe true, and not mean longitudes, van der Waerden shows that it was not at all necessary for Āryabhaṭa to observe mean longitudes. Supposing that Āryabhaṭa had tables from which to calculate mean and true longitudes for his own time and he had really computed them to find discrepancies between the observed and calculated positions how would he proceed to make his system work? "He might", says van der Waerden, "make appropriate changes in the elements of the table, and calculate the positions anew. After one or two trials, he would probably get a reasonable agreement between calculation and observation. There was no need for him to calculate mean longitudes from observed positions."[135] That Āryabhaṭa really proceeded in this manner is strongly indicated in Billard's analysis of Āryabhaṭa's mid-night and sun-rise systems. In the former all mean longitudes are good for A.D. 510 except those for Mercury and Jupiter. Supposing Āryabhaṭa wanted to improve upon his Jupiter it would have been easier for him to observe the planet 'for some time, say one or two synodic periods of thirteen months each, and see what changes in the mean longitudes and other elements he had to make in order to reach a better agreement between theory and observation'. Billard actually prepared a diagram showing deviations of true longitudes of Jupiter and Saturn computed on the mid-night system from those due to modern theory and tables for the years between A.D. 507 and 513 and made it available to van der Waerden. The diagram shows for Jupiter a more or less constant deviation between—1°10′ and—1°40′ and a superimposed sine wave of period equal to that of Jupiter. The constant deviation and the sine wave could be rectified by increasing the mean longitude by the amount of deviation and at the same time

changing the dimension of Jupiter's 'conjunction epicycle'. Van der Waerden says, "Now this is just what Āryabhaṭa did. In the Mid-night System, the number of revolutions of Jupiter in a *Mahāyuga* was 364, 220, but in the *Āryabhaṭīya* it was raised to 364, 224, which means that the mean longitudes for the lifetime of Āryabhaṭa were augmented by 1°12'.....In the Midnight System the circumference of this epicycle was 72 degrees, i.e. its radius was the $\frac{72}{360}$ of the radius of the deferent. In the *Āryabhaṭīya* the figure 72 was retained for the initial points of the odd quadrants of the epicycle (i.e. at the opposition and conjunction), but reduced to 67½ at the initial points of the even quadrants, where the sine wave has its maxima and minima. This reduction of the size of the epicycle was just sufficient to eliminate the sine wave, as Billard's calculations show clearly."[136]

Observational basis is also strongly indicated in Billard's analysis of Brahmagupta's *Brāhmasphuṭasiddhānta*. Although the text was written in A.D. 628 the planetary observations underlying the system appear to have been made near the middle of the sixth century and those of the Sun and the Moon near the end of the century. Van der Waerden carried out his own calculations to confirm these conclusions. Āryabhaṭa's mean longitudes set right for A.D. 510 as explained above would deteriorate progressively (mean motions would be slow), and show up large errors in the case of Mars, Saturn, Jupiter and Venus after nearly a century. "Now Brahmagupta, or his predecessor, who corrected Āryabhaṭa's mean motions", observes van der Waerden, "never diminished, but always augmented the mean motions. He added four units to Āryabhaṭa's number of revolutions for Mars, three for Saturn, two for Jupiter and one for Venus, just in the right order. This proves that the observations, on which these corrections to Āryabhaṭa were based, were made sometime after Āryabhaṭa, say about A.D. 570."[137] That these corrections were necessitated by observations was stated by Brahmagupta himself (*Br. Sph. S.* XI, 51).

In addition to the speculative canons based on imaginary conjunction of planets in February 3102 B.C., where the errors increase with time, Billard discovered three 'non-speculative' canons (canons exempts de spéculation) independent of any such supposition. These are Lalla's *Śiṣyadhīvṛddhidatantra* (K. (Lalla)), and two versions A and B of *Grahacāranibandhanasaṃgraha* (K. (GCNibs) A, K. (GCNibs) B). The first canon of this family, K (Lalla), for example, derives its mean motions by comparing Āryabhaṭa's values correct for his time with a set of new observations made around A.D. 898. The result is that the canon yields accurate sidereal longitudes of all planets except Mercury for a period of 500 years between A.D. 400 and A.D. 900. The other two canons operated likewise between values correct for A.D. 522 (assuming Āryabhaṭa's mean values to be correct for this date) and the same observed values for A.D. 898 used by Lalla. The deviation curves in longitudes and synodics obtained for this family of three are more or less identical and resemble those for the *Almagest*. Billard says that from the view point of realism, objectivity and precision, these texts achieved what was possible in their epochs. "Le réalisme y est cette fois aussi complet qu'il pouvait l' être dans l'astronomie ancienne. La spéculation disparait

enfin pour laisser place a des canons tout objectifs, tout comme le K. $M\alpha\theta\Sigma\upsilon\nu\tau$ *(Almagest)* (2, 2, 2) des figures 1 et 2, et de plus d'une precision qui était sans doute à la limite des moyens de l'époque."[138] Van der Waerden points out that Pingree criticizes Lalla's work to be "very crude", but "does not mention the fact that Lalla's mean motions are excellent for the whole period from A.D. 400 to 900." He also avoids noting Billard's date of A.D. 898 when actual observations were made as the basis of these non-speculative texts, and sticks to his own dating of Lalla's work in favour of eighth or early ninth century without giving any reason.

To suit his own theory Pingree devised a number of chronological schools, e.g. the *Brahmapakṣa,* the *Āryapakṣa* etc. The *Brahmapakṣa* of which the basic text was the *Paitāmaha-siddhānta* is supposed to precede *Āryapakṣa,* and the *siddhānta* which is placed in the early fifth century is assumed to be the source and inspiration of Āryabhaṭa's work, for which the last verse (IV. 50) of the *Āryabhaṭīya* is adduced as evidence. Billard considered this last verse in detail, found it to be incompatible with the spirit of the work, and unhesitatingly declared it to be an interpolation. *Paitāmaha-siddhānta*'s placement in the early 5th century has also been called into question. The revolution numbers given in this work are the same as those given by Brahmagupta. Furthermore, the calculations made by Billard and van der Waerden indicate that these numbers were based on observations made in the late sixth century.' Van der Waerden, therefore, considers Pingree's dating 'in the early fifth century as impossible.[139]

In concluding his review of the two treatises, van der Waerden observes that 'Billard's methods are sound, and his results shed new light on the chronology of Indian astronomical treatises and the accuracy of the underlying observations.'[140] We ourselves would like to conclude this survey by expressing a hope that Billard's method of computerized statistical analysis should be followed in many more studies of this kind for a better and more thorough understanding of the history of astronomy in ancient and medieval India.

4 ASTRONOMY IN INDUS CIVILIZATION AND DURING VEDIC TIMES

A. K. BAG

Primitive civilizations recognized the fact that different constellations are visible at different times of the year. The appearance of conspicuous stars or groups of stars in conjunction *(amāvasyā)* or opposition *(pūrṇimā)* with the Moon or Sun was considered to be reliable guides for the fixing of agricultural and religious practices. Scientific astronomy in India perhaps began with the use of such astronomical phenomena. Many religious festivals in India are still found to be associated with the phases of the Moon *(tithi)*—an association which thus acquired a deeper significance. India, like Egypt and Mesopotamia, originally had a lunar calendar in the time of the Indus civilization. In Vedic and post-Vedic times, the Sun gradually assumed greater importance because of the emphasis on agriculture and seasons. Consequently the attempt in the Vedic period to associate the lunar months in a more or less fixed fashion with the agricultural seasons led to the development of a luni-solar calendar in the post-Vedic period. The luni-solar calendar involved the addition from time to time of an intercalary lunar month to the regular (civil) months of fixed length (of 30 days). These intercalations were handled in a practical manner, whenever deemed necessary, to ensure that seasonal festivals and agricultural practices did not go out of step. Methods of intercalations varied over different parts of the country.

NEW YEAR FESTIVAL

Parpola and his colleagues have studied the astronomy of the Indus civilization.[1] This was later re-examined by Asfaque.[2] These scholars believe that various figures of animals, real or mythological (bulls, elephants, rams, rhinoceroses, crocodiles, tigers, unicorns, animals with composite head etc.) and deities in human form, found in Indus seals, signify a crude system of the division by asterism of the apparent path of the Moon. Father Heras[3] first associated the sign () with the Dravidian word *min* for fish, and its homophone signified an asterism. Parpola *et al.* also supported this dual system of interpretation of star worship and fish cult which was probably based on the concept that the sky was garbed by the oceans or a broad river in which the stars were nothing but the swimming fishes. The proper assessment of the extent of astronomical knowledge, however, must await the decipherment of all the seals.

Our knowledge about the new year festival of the Indus people is based on the depiction on a seal (M. 2430) found in the D. K. area Mohenjo-daro. This seal demonstrates how religious ritual and astronomy went hand in hand in these distant prehistoric times. The Vedic period also records similar offering ceremonies such as

the *sāvana* (thrice a day), the *aha* (daily sacrifice from sunrise to next sunrise), the *saḍaha* (six *ahas*), the *māsa* (five *saḍahas*), and the *samvatsara-satra* (twelve *māsas*). The important pictographs on the Mohenjo-daro may be described as follows:

(i) a deity standing at the central place between two similarly inclined branches of a pippal tree; (ii) in front the deity there is a raised structure, perhaps an altar; (iii) seven other human figures standing in a row in the lower portion of the seal in such a way that the deity, the altar and the central human figure apparently come in one line denoting perhaps east-west; (iv) a priest kneeling before the altar; (v) the picture of a huge stag or ram with two long heavy horns having a human face; (vi) the head-dress of all human figures resembles the traditional Indian turban; and (vii) several pictographs include the fish symbol (Fig. 4.1).

Fig. 4.1

What do the seven human figures represent? Parpola[4] writes, "I was previously thinking that the seven figures in the seal (M. 2430) most probably are seven sages of the Great Bear. I have later changed my view, and now think that they are probably the stars of Pleiades. The conclusion, however, is not based on the seal, but on studies of the Vedic and Epic mythology and the connection of Skanda with the Pleiades, also in the Indus script". Moreover, Parpola considers the representation on the seal to be the new year festival with autumnal equinox at the full-moon at Kṛttikā, while Asfaque compares it to the vernal equinox at Kṛttikā. In fact, Harappan-Ṛgvedic and Mohenjo-daro Atharvavedic cultural traditions have been

emphasized by many historians. According to the Vedic tradition,[5] Kṛttikā comprises of seven stars, viz. Ambā, Dulā, Nitatnī, Abhrayantī, Meghayantī, Varṣayantī and Cupunikā. The *Śatapatha Brāhmaṇa*[6] reports that Kṛttikā never deviates from the east. The actual east-west line might have been determined by the shadow of the pole on the equinox day and verified by the rising and setting points of the star Kṛttikā.[7] The fixation of east-west line also played a significant role in the construction of Vedic altars. At present, Kṛttikā does not appear to rise exactly in the east but at a point north of east. Obviously the lower portion of the seal represents the eastern sky.

In the western side is found a handsome, ever-young god between the two pippal branches. The symbol of branches appears to be meaningful, for in Sanskrit the word *śākhe* means two branches of a tree. Hence the symbol is of special significance and represents possibly the asterism Viśākhā. This again becomes clear from the fact that Viśākhā and Kṛttikā are opposite constellations (*vide* table of the lunar mansions). The handsome figure between the two branches shows that he is in conjunction with Viśākhā. Parpola considers the handsome ever-young war-god as Skanda, the heavenly counterpart of Viśākha, while Asfaque is inclined to think that it represents the Moon in its dark phases and invisible to the eye at the epoch of the new year.[8] From the prominent crescent horn and beautiful ever-young feature it is quite suggestive that the god represents 'Moon' not war-god 'Skanda'. The presence of Kṛttikā in the eastern horizon suggests that the full-moon rises at Kṛttikā and sets at the opposite asterism Viśākha. So the ending part 'Moon in the dark phases' does not appear to be correct. This is perhaps the last hour festival of the night after it began its journey with full-moon at Kṛttikā. In the centre of the seal is found a man worshipping before an altar. At the back of the priest, there is the figure of a huge stag (in Sanskrit, *mṛga*) with two big horns *(śiras)*. The stag on the seal is represented as the asterism Bharaṇī and Aśvinī both by Parpola and Asfaque on the basis of the hypothesis that they are situated west of Kṛttikā, and their place in the sky is much higher above the eastern horizon than that of the former at the time of the heliacal observation. The star *mṛga* is described in masculine gender in the *Atharvaveda*[9] and the ceremony shows that the priest is introducing Mṛgaśīras which is known as the month of Agrahāyanī in the Vedic tradition.[10] The Agrahāyanī derives its meaning, from the following: "the year *(hāyana)* stood at the end *(agra)* of that *nakṣatra* night". Agrahāyanī as a synonymous term for Mṛgaśīrṣa *nakṣatra* occurs in Pāṇini at three places.[11] There are references at two places in the *Mahābhārata*[12] to the effect that the list of months begins with the Mārgaśira. Al-Bīrūnī[13] has recorded that, in Sind and other provinces, the year commenced with the Mārgaśiras, and the system of bearing the year with Mārgaśiras must have remained in vogue in some provinces in west India for some time. The stag *(mṛga)* is so prominent on the seal as to make it highly probable that the months of Agrahāyani were already introduced in Indus times. This again shows that the *kṛttikādi* system was current during the Indus Valley civilization. The new year began with Kṛttikā on the equator (equinoxial day), and the month was *pūrṇimānta*. The remaining symbols of the seal (M. 2430) have been considered by Parpola and his colleagues as ritualistic paraphernalia on the occasion of the year beginning.

LUNAR MANSION AND LUNAR MONTHS

From the foregoing discussion it appears that the months Mṛgaśīrṣa (Agrahāyanī) were being introduced after the full-moon at the Kṛttikā (*kṛttikādi* system). Further, Kṛttikā was considered as the east point on the equator or equinox point when day and night were equal. The months were also *purṇimānta*. The month-names, Kārttika, Agrahāyanī (Mṛgaśīrṣa), Pauṣa, Māgha, etc. directly follow from the star names Kṛttikā, Mṛgaśīrśa, Puṣyā, Maghā respectively. Moreover, the identification of Kṛttikā and Viśākhā asterisms in opposition indicates that possibly 27 or 28 asterisms were already known in time of the Indus civilizations. The *Atharvaveda*[14] and the other Vedas[15] have followed the *kṛttikādi* system and given also a complete list of 27 or 28 lunar asterisms. The tradition of the system of *nakṣatras* and lunar months based on them is very old. The details are tabulated as follows:

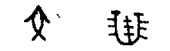
Nakṣatra (*Nirayana* Longitude)[16]	*Lunar months*
1. Kṛttikā (Alcyon, 36° Long)	Kārttika
2. Rohiṇī (Aldebaran, 46°)	Agrahāyanī
3. Mṛgaśīrṣa (λ Orionis, 60°)	
4. Ārdrā (Betelguese, 65°)	Pauṣa
5. Punarvasu (Pollux, 90°)	
6. Puṣyā (δ Cancrii 105°)	
7. Āśleṣā (Hydras, 99°)	
8. Maghās (Regulas 126°)	Māgha
9. (Pūrva) Phalguni (δ Leonis, 138°)	Phalguni
10. (Uttara) Phalguni (Denebola, 148°)	
11. Hasta (δ Corvi, 170°)	Caitra
12. Citrā (Spica, 180°)	
13. Svātī (Arcturus, 181°)	Vaiśākha
14. Viśākha (α Centauri, 216°)	
15. Anurādhā (δ Scorpi, 219°)	Jyaiṣṭha
16. Jyeṣṭhā (Antares, 226°)	
17. Mūla (λ Scorpii, 241°)	
18. (Pūrva) Aṣādhā (δ Sagittarii, 251°)	Āṣāḍa
19. (Uttara) Aṣādhā (δ Sagittarii, 259°)	
20. Abhijit (Vega, 262°)	
21. Śroṇā (Altair, 278°)	Śrāvaṇa
22. Śraviṣṭhā (β Delphini, 293°)	
23. Śatabhiṣā (λ Aquarii, 318°)	
24. (Pūrva) Proṣṭhapadā (Markob, 330°)	Bhadrapadā
25. (Uttara) Proṣṭhapadā (ν Pegasi, 346°)	
26. Revatī (ζ Piscium, 356°)	
27. Aśvayujau (β Arietis, 10°)	Āśvina
28. Bharaṇī (41 Arietis, 25°)	

ORIGIN AND CONFIGURATION OF THE UNIVERSE, STARS AND PLANETS

The ideas of the Indus Valley people on the origin and the configuration of the universe are not yet known. The *Ṛgveda*[17] mentions: "From the watery ocean was born the year *(samvatsara)* ordaining days *(aha)* and night *(rātri)*, the controller of every living moment. The creator then created, in due order, the Sun *(sūrya)*, the Moon *(candra)*, the sky, the regions of air and light". Similar passages are found in the *Taittirīya Brāhmaṇa*[18] and the *Taittirīya Upaniṣad.*[19] Though in some passages the Vedas describe the creation of the world and the order of creation, doubt has also been expressed in various passages of the *Taittirīya Brāhmaṇa*[20] where it is pointed out that no one can say the actual cause of creation, which implies that no one knows the order in which the creation took place.

Some time the universe has been stated to be made up of the earth and sky *(dyāvā pṛthivī)*, but more often it is referred to as consisting of three parts,[21] viz. earth *(bhūmi)*; the atmosphere *(antarikṣa)* and the sky *(dyau)*. The universe is also conceived as infinite in extent.[22] The *Taittirīya Saṃhitā*[23] notes that fire rests with the earth, air in the atmosphere, Sun in the sky and Moon in the company of constellations *(nakṣatrebhyaḥ)*.

The *Ṛgveda* refers to the five planets as the five gods[24] and mentions Bṛhaspati (Jupiter) and Vena (Venus) by name.[25] It also mentions the thirty-four lights[26] which, in all probability, are the Sun, Moon, the five planets and twenty-seven *nakṣatras*. Parpola considered the crab symbol as indicative of planets because of its occurrence in samples in most cases before and after various fish signs of Indus inscriptions. The Tamil word, *kol* for planet also means 'to seize' or 'seizure' giving emphasis on the claws rather than on the feet. The Sanskrit word *graha* for planets has also the same meaning. This indicates that the Vedic people received the pre-*Ṛgvedic* traditions of the Indus civilization.

The Indus script () has been accepted by Parpola to signify *vaṭa-min*in old Tamil, signifying "north star". Vedic seers knew certain other constellations, e.g. Ṛkṣas (bears), meaning possibly two north polar constellations, the Great Bear and the Little Bear[27]; two heavenly dogs identified with Canis Major and Canis Minor[28]; the divine boat signifying the constellation of Navis.[29] The Great Bear was also known as the constellation of seven sages, *saptarṣi*.[30] The *Aitareya Brāhmaṇa*[31] has narrated an interesting story regarding the constellation Mṛga (Orion) with the star Mṛgavyādha (Sirius).

The Sun is conceived as the prime supporter and controller of the world as well as sole lord and light-giver of the universe.[32] The Sun also controls the seasons and causes the winds.[33] It further generates all earthly directions.[34] There is reference to only one Sun and not more as the lord of the universe.[35] The Sun is considered as the maker of the day and night; the duration of day light from sun-rise to sun-set is

taken as the day" and that of darkness from sun-set to sun-rise as the 'night'. The variability of the length of day and night was also known.

The Moon is spoken of as the light of the Sun *(sūrya-raśmi)* meaning that it shines by the Sun's light.[36] It is as bright[37] as the Sun and appears in new forms day after day in different phases.[38] Some phases[39] are well-known, e.g. "full-moon day *(rākā)*, the day previous to full-moon *(anumati)*, new-moon day *(kuhū)*, the day preceding the new-moon *(sinīvālī)*. The *Taittirīya Brāhmaṇa*[40] gives a full list of names of fifteen days of the light half *(pūrva pakṣa)* and also of dark half *(aparapakṣa)* of the Moon. Day and night is each divided into fifteen *muhūrtas*. Each *muhūrta* is again divided into fifteen *pratimuhūrtas*.[41]

The period from one moonrise to the next or from one moon-set to the next was known as a *tithi*[42] (lunar day) in the Vedic period, which is somewhat different from our present concept of a *tithi* of fixed time. That the phenomenon of new- and full-moon is related to Moon's elongation from the Sun was also correctly guessed. The invisibility of the Moon on the new-moon day is explained by its being swallowed by the Sun and its appearance on the following day by its being released by the Sun.[43]

UNIT OF TIME

The year *(samvatsara)*, month *(māsa)*, six days week *(ṣaḍaha)* and day *(aha)* were considered as basic units of time. There were various units of year lengths known in ancient India, a few of which are summarized below :

1. Sidereal *(nākṣatra)* lunar year of 324 days=27 *nakṣatras* of 12 days average duration each. The number was possibly derived from the practical counting of the moon through *nakṣatras*.

2. Sidereal *(nākṣatra)* lunar year of 351 days=27 *nakṣatras* of 13 days average duration each.

3. Synodic (similar position of the Moon relative to Sun) lunar year of 354 days $= 6 \times 30$ days$+ 6 \times 29$ days
$= 12 \times 29\frac{1}{2}$ days.

   For practical consideration, the first half of the six months was possibly considered to be of 30 days and the second half of 29 days. The average lunar month contains $\frac{1}{12}$ $(6 \times 30 + 6 \times 29)$ or $29\frac{1}{2}$ days. The Moon becomes full after 29 or 30 days.

4. Civil *(sāvana)* year of 360 days $= 12 \times 30$ days
$= 12 \times 5$ *ṣaḍahas* (1 *ṣaḍaha* $= 6$ days)
$= 360$ days.

This refers to the mean motion of the Earth round the Sun. The *Ṛgveda*[44] has compared 12 months to 12 spokes of a wheel, 360 days to 360 nails, and describes day and night as couple, and 360 such couples give the number 720. The *Taittirīya Saṃhitā* gives 360 *stotriyas* (verses) for recitation for 360 nights.[45]

5. Sidereal *(nākṣatra)* solar year of 366 days$=27 \times 13\frac{5}{9}$ days. The Sun was considered to remain in each *nakṣatra* $(13+\frac{1}{3}+\frac{2}{9})$ days $= 13\frac{5}{9}$ days. This refers to the revolution of the Sun with reference to a fixed star. The *Nidāna-sūtra*[46] gives a summary of all these year length.

The *Ṛgveda*[47] states that Varuṇa knew the 12 months and the animals created during that period as also the intercalary month which used to be created (near the 12 months). In the *Taittirīya Saṃhitā*[48] there is a passage which says that a day is omitted after some *ṣaḍahas* (six day week), and *māsas* are observed. It indicates the circumstances in which the day is omitted during the period. The lunar month is equivalent to $29\frac{1}{2}$ days, two such months are equivalent to 59 days. Therefore, if a *ṣaḍaha* ceremony is commenced on the first day of the lunar month, the second lunar month would end one day earlier. This shows that attempts for intercalation were made in Vedic times to adjust the lunar month or year agreeing with the civil year and the seasons. The *Ṛgveda*[49] points out that the year occasionally has a thirteenth or additional month which is produced of itself. Shamasastry[50] explains that a cycle of three *sāvana* years of 360 days each was followed by a year of 380 days. As a result the four-year period contained 1461 days, each average civil year being $365\frac{1}{4}$ days.

The natural means of measuring a year originated from the experience of periodic recurrence of climatic seasons. Likewise the natural means of measuring a day was the period between two consecutive sun-rises, and that for a month a period between two full-moons. The return of the Sun to the same position with respect to the fixed stars might have appeared to be much more reliable than the slow seasonal variation of the length of day light. There appears to be a constant attempt at adjusting the lunar months with the seasons. The idea of intercalating a month at regular intervals of time or of adding of 5 or 6 days in one month or more months was thus developed. Naturally, three units of time measurement, viz. the solar day, the lunar month, and the solar year are involved. Consequently, the luni-solar adjustment depended on the problem of finding the integers x, y, z, which satisfy the relation

$$x \text{ years} = y \text{ months} = z \text{ days}$$

This type of adjustment was attempted in late Vedic and the *Vedāṅga Jyotiṣa* period.

A bigger unit of time of five years known as *yuga* was also conceived for this adjustment. The *Taittirīya Brāhmaṇa*[51] states thates that five years, viz. *samvatsara, parivatsara, idāvatsara, iduvatsara* constituted the *yuga*. We find mention of two year names also in the *Ṛgveda*[52] and all names with little variations appear in the *Yajurveda*.[53] The conception of *caturyuga* and *kalpa* were possibly later developments,

LUNAR MONTHS, SEASONS AND SOLAR MONTHS

The Sun generates all the earthly directions and controls the seasons.[54] The *Taittirīya Saṃhitā*[55] gives the names of the following seasons and corresponding solar months.

Lunar months	*Seasons*	*Solar months*
Caitra	Vasanta (Spring)	Madhu
Vaiśākha		Mādhava
Jyeṣṭha		
	Grīṣma (Summer)	Śukra
Āṣāḍha		Śuci
Śrāvaṇa		
	Varṣā (Rains)	Nabha
Bhādrapadā		Nabhasya
Āśvina		
	Śarada (Autumn)	Iṣa
Kārttika		Urja
Margaśīrṣa (Agrahāyaṇa)		
	Haimanta (Dewy)	Saha
Pauṣa		Sahasya
Māgha		
	Śiśira (Winter)	Tapa
Phālguna		Tapasya

The lunar month used to be measured from full-moon to full-moon or from new-moon to new-moon as it is now; it was more widely known because of its association with festivals. More-over, it was easy to measure a lunar month, while the method of computating a solar month was not an easy task.

SOLSTICES (AYANAS) AND EQUINOXES

During the time of Mohenjo-daro, the new year began with the end of Kārttika *purṇimā*. This marked the equinoctial day, the day of yearly sacrifice, as well as beginning of year and of *yuga*. The *Kauṣitakī Brāhmaṇa*[56] reports that the Sun rests on the new-moon day of Māgha *(māghi-amāvasyā)* being about to turn towards north. On this day the *mahāvrata* rites were performed. This refers to winter solstice day. From the statement of the *Vedāṅga Jyotiṣa* that the solstices coincide with Āśleṣā *(māghi amāvasyā)* and Dhaniṣṭhā *(śrāvaṇa amāvasyā)*, the vernal equinox appears to have coincided with Bharaṇyaḥ *(kārttika amāvasyā)*. The system of new year definitely changed from *pūrṇimānta* to *amānta* system. This fact was observed though it does not follow from this that the Indians knew the phenomenon of precession. The shift from *kārttika pūrṇimā* to *kārttika-amāvasyā* is due to precession of equinoxes and is about 15 *tithis*, (1 *tithi* difference $=72$ years, 15 *tithis* $= 15 \times 72$ years $= 1080$ years).

From *māghi-amāvasyā* day the Sun goes towards north for six months, stands still and then turns towards south. On this day, when it was turning towards south, the rites of *vaiṣuvatīya* (summer solstice) are performed. Thus the year is divided into two halves of six months marked by winter solstice and summer solstice. The increase in day-lengths and corresponding decrease in lengths in night from winter solstice to summer solstice are noted in later texts, the longest day-length at summer solstice being 18 *muhūrtas* and the shortest day-length at winter solstice being 12 *muhūrtas*.

The *Taittirīya Saṃhitā*[57] also notes that the Sun moves northwards *(uttarāyaṇa)* for six months and southwards *(dakṣiṇāyana)* for six months. These progresses are referred to also in the *Ṛgveda*[58] and in the *Atharvaveda* as *Devayāna* and *Pitṛyāna*. The later astronomical texts mention these movements as *uttarāyaṇa* (northern movement) and *dakṣiṇāyana* (southern movement).

5 POST-VEDIC ASTRONOMY

S. D. SHARMA

Vedic astronomy has a long span starting from remote antiquity upto the advent of siddhāntic texts. Vedic astronomical lore can be seen in the earliest strata of the *Ṛgveda*. We find an ancient report on conjunction of Jupiter with δ Cancri (Tiṣya or Puṣya Yogatārā) in the *Taittitrīya Saṃhitā*,[1] *Tāṇḍya Brāhmaṇa* etc. which can be shown to belong to a naked eye observation around 4650±80 B.C. on the basis of slow motion of the node of Jupiter's node over δ Cancri region.[2] There are ancient observations of Moon recorded in the *Ṛgveda*, which paved the way to five-year yuga system in calendar making. Although such ancient records are available in oral traditional literature of the Vedic times, yet there was no systematic text compiled earlier than 1400 B.C.[3] or so, when Ṛṣi Lagadha compiled *Vedāṅga Jyotiṣa* (*V. J.*). In fact there is a big gap of about twot housand years between *V. J.* and the siddhāntic tradition of Āryabhaṭa (last decade of 5th century A.D.). After *V. J.* we find Jaina canonical literature *Sūrya-candra prajñapti*, *Jyotiṣkaraṇḍaka* and Buddhist literature *Śārdūlakaraṇāvadāna* etc. *Pañcasiddhāntikā*, a compendium by Varāhamihira of five astronomical treatises, some ancient and some of comparatively recent times. In addition to this we find also the qualitative studies of kinematics of planets Mars, Mercury, Jupiter, Venus and Saturn in *Bṛhat-saṃhitā* and *Bhadra-bāhu Saṃhitā* etc.[4] These have also reports on cometary kinematics and include old analytic records on studies of meteors.

PLANETARY KINEMATICS

The planetary kinematics reported in *Bṛhat-saṃhitā*, *Bhadrabāhu Saṃhitā* and other saṃhitā texts are very primitive and qualitative and seem to be quite old. It is often commented that *V. J.* had only studies of kinematics of Sun and Moon before contacts with Greeks, but these reports on planetary kinematical studies indicate a good deal of attempt on studies of planetary velocities, retrogradations, their heliocentric rising and setting and conjunctions with stars etc.

Here we have tabulated (Table 5.1) the categorizations of retrograde motions of Mars. The study of motion was started whenever the planet became first visible after combustion. The number of asterisms between the point of first visibility and the point of retrogradation was reported and various names were assigned to Mars accordingly. For example, if it is retrograded in the 7th, 8th or 9th asterism after first visibility it was named "*Uṣṇa-Mukha*" according to *Bṛhat-saṃhitā* of Varāhamihira and Bhadrabāhu and "*Vakra-Mukha*" according to Vṛddha Vasiṣṭha. These names, though they have astrological prognostications, deserve critical analysis of the qualitative kinematical data,

Table 5.1

Categorization of Retrograde motions of Mars

Number of asterisms where it retrogrades (with respect to the asterism where it becomes first visible after combustion)	Varāhamihira & Bhadrabāhu	Vṛddha Vasiṣṭha
(1) In 7th, 8th & 9th asterisms	*Uṣṇa-Mukha*	*Vakra-Mukha*
(2) In 10th, 11th and 12th asterisms	*Soṣa-Mukha*	*Asru-Mukha*
(3) In 13th & 14th asterisms	*Vyāla-Mukha*	*Vyāla-Mukha*
(4) In 15th & 16th asterisms	*Lohita-Vakra*	*Raktānana*
(5) In 17th & 18th asterisms	*Loha-Mudgara*	*Musala*

Here as an example of study of motion of Mercury, we have tabulated three different categorizations of its velocities according to Parāśara Devala and Bhadrabāhu (Tables 5.2, 5.3 and 5.4) which seem to be gradual improvements in study of the motion of Mercury. The velocity was given names like *Ṛjvī, Ativakrā* etc. (see table 5.2) *Prākṛta, Vibhinnā,* etc. (see table 5.3) depending upon the number of days this planet took for its combustion. Its *Ṛjvi* (direct) velocity is for 30 days, *Vakrā* and *Vikalā* (stationary), velocity was noted to be for 6 days. The categorizations found in *Bhadrabāhu Saṃhitā* seem to be much improved (Table 5.4). All these qualitative data deserve critical mathematical analysis.

In the case of Jupiter too we find the study of its direct and retrograde motions. The motion was studied between its consecutive heliocentric risings. These studies yield sidereal time period of Jupiter$\simeq$12 years and on combining this period with Five Year Yuga, a 60-year cycle was designed. These consecutive 60 years are given different names and have much importance in Hindu religious calendar.

Table 5.2

Categorization of Mercury's velocities according to Devala

Type of velocity	No. of days of combustion or visibility
1. *Ṛjvi*	30 days
2. *Ativakrā*	24 days
3. *Vakrā*	12 days
4. *Vikalā*	6 days

Table 5.3

Categorization of Mercury's velocities according to Parāśara

Type of velocity	No. of days of combustion or visibility
1. *Prakṛtā*	40 days
2. *Vibhinnā*	30 days
3. *Saṃkṣiptā*	22 days
4. *Tīkṣṇā*	18 days
5. *Yogāntikā*	9 days
6. *Ghorā*	15 days
7. *Pāpā*	9 days

Table 5.4

Categorization of Mercury's velocities according to Bhadrabāhu

1. *Saumyā*	45 days
2. *Vimiśrā*	30 days
3. *Saṃkṣiptā*	24 days
4. *Tīkṣṇā*	10 days
5. *Ghorā*	6 days
6. *Pāpā*	3 days
7. *Durgā*	9 days

In the case of Venus the kinematical studies are very interesting. In Saṃhitās and in Jaina literature we find the study of motion based on estimates of its average velocities during heliacal combustion in different parts of the lunar zodiac.[5] During combustion Venus moves in lanes *(vīthis)* among stars. There are 9 lanes in all which are defined by the number of days it is heliacally invisible during inferior and superior conjunctions (Table 5.5). The lanes have definite *nakṣatras* starting with Aśvinī, Bharaṇī and Kṛttikā in Nāga[6] *vīthi* (not listed in table 5.5). The table also has zodiacal stretches listed for the case of inferior conjunction in units of *muhūrtas* of arc (1 *muhūrta*=the angular distance travelled by Moon in 48 minutes, and $819\frac{27}{67}$ *muhūrtas*=360°).

Table 5.5

Vīthi	Number of days for which Venus remains heliacally invisible		Zodiacal stretch
	Inferior conjunction	Superior conjunction	Muhūrtas of arc (Inferior conjunction)
1. *Vaiśvānara* (fire)	24	86	$84\frac{27}{67}$
2. *Mṛga* (deer)	22	84	75
3. *Aja* (goat)	20	86	120
4. *Jaradgava* (old bull)	17	75	105
5. *Go* (cow)	14	70	90
6. *Vṛṣa* (bull)	12	65	90
7. *Airāvata* (chief elephant)	10	60	75
8. *Gaja* (elephant)	8	85	105
9. *Nāga* (snake)	6	55	75

The names of *vīthis* indicate qualitative nature of the speed estimates. Still it can be shown that the perigee of Venus's orbit lies in *Vaiśvānara vīthi*.

In the case of Saturn the time period was estimated to be 30 years (approximately). All these studies on planetary kinematics, being qualitative, indicate their pre-siddhāntic chronology.

There are also studies on cometary statistics in Saṃhitā texts. It is undoubtedly true[7] that Indian astronomers believed in the periodicity of comets long before Edmund Halley claimed it for the comet observed in 17th century A.D. and known after him. Bhaṭṭotpala (A.D. 937) in his commentary on *Bṛhatsaṃhitā (Ketu-carādhyāya)*, gives a list of comets with their names after the names of Ṛṣis who studied their motions and recognized their reappearance in their lifetimes probably using previous records. Although *Bṛhatsaṃhitā* starts its chapter on comets with a general statement that the cometary motions cannot be computed, yet it lists definite loci of some comets in the lunar zodiac. Similarly other Saṃhitā texts and literature too give definite orbits of some comets and it is contemplated that these records have reports on old apparitions of Halley's comet. T. Kiang of China has decoded 29 apparitions of Halley's comet before 17th century A.D. in Chinese tradition (*Memoir of Royal Astronomical Society of England,* 1976), J. Brady of California has tried to decode still older records in European tradition, but the records before 240 B.C. are not much reliable. Indian records too can be decoded for such old reports on apparitions of Halley's comet,

Jaina Astronomical Tradition

The Jaina canonical text *Sūrya-prajñapti*, *Jyotiṣkaraṇḍaka*, etc. have records of pre-siddhāntic post-Vedic astronomical traditions. Although these records were compiled in the form of these texts quite late, there is no doubt that the observational records presented in *Sūrya-prajñapti* etc. belong to 2nd century B.C.[8] or even to an earlier period. We call the period between the *Vedāṅga Jyotiṣa* and siddhāntic astronomy to be the dark period, as these texts indicate no further advancement in Indian astronomical tradition partly, due to the reason that texts like *Sūrya-prajñapti* of this period are not well understood. These are undecoded due to the fact that the old tradition of ancient pre-siddhāntic astronomy was forgotten with the advent of siddhāntic astronomical schools.

Even Brahmagupta[9] and also Bhāskarācārya criticized the double counter Sun hypothesis of the Jainas. It may be remarked that now the paradox of two Suns is resolved and it has been shown that the relevant *gāthās* in *Sūrya-prajñapti* in fact belong to the daily astronomical observations of the Sun at the time of rising and setting.[10] These observations were meant for the experimental determination of the solar year. This post-Vedic tradition of Indian astronomy is very important and it has been decoded that the confusion regarding existence of two Suns resulted because the word *ardhamaṇḍala* for half of the diurnal path of the Sun got interpreted to mean the cutting of a *maṇḍala* (diurnal path) in two halves perpendicular to its surface. This is the traditional interpretation by Malayagiri and others (Fig. 5.1). Even Malayagiri[11]

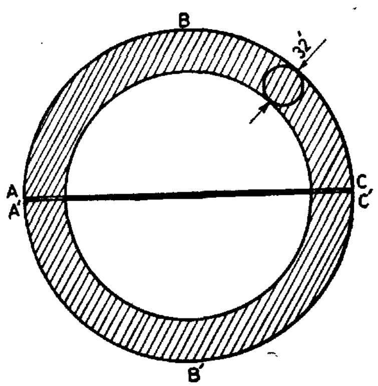


Fig. 5.1. The maṇḍala is the disc of sun, but this word now stands for the locus generated by the sun in diurnal motion; the word Ardha-maṇḍala (half of a maṇḍala) was taken to be half section as shown above.

accepts the inadequacy of his interpretation this way and begs pardon if that proves wrong in future. Now it has been shown on the basis of mathematical details and the linguistic approach that the word *ardhamaṇḍala* means a cross section of wheel like structure of diurnal path *(maṇḍala)* into two halves of half the width each, without distorting its circular structure as shown in Fig. 5.2. *Sūrya-prajñapti* states that the

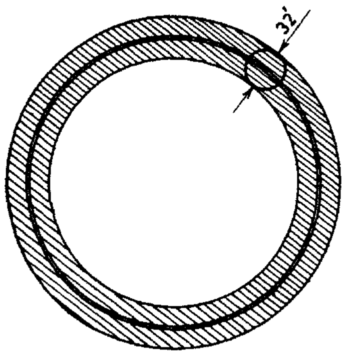


Fig. 5.2. In our interpretation the word *ardha-maṇḍala* a stands for the cross-section of this wheel like path. This *ardha-maṇḍala* is traversed by the sun in one day on an average or near equater. Radius of the disc being 16'.

Sun (on an average) traverses half of the *maṇḍala* (i.e. half of its own disc and consequently the wheel like locus generated in diurnal motion) every day, which is true taking into consideration the mean declinational *uttarāyaṇa* and *dakṣiṇāyana* (north south) motion of the Sun. There are shown plots of daily observations of the Sun in the morning and evening, which created confusion for two Suns. On the basis of these experiments, the solar year was determined to be of $365\frac{1}{5}$ days[12] which is found also reported in *Paitāmaha Siddhānta* in *Pañca siddhāntikā* of Varāhamihira. This length of solar year is not found used as there were not really a break-through in theoretical advancements in the dark period.

The Early Traditions of Siddhāntas

After post-vedic pre-siddhāntic developments, we find five schools as compiled by Varāhamihira in his *Pañcasiddhāntikā*. Out of the five siddhāntas the *Paitāmaha-siddhānta* is the earliest of all and belongs to the epoch of 11th Jan. 80 A.D.[12] Its elements have direct connection with *Vedāṅga-jyotiṣa* of Lagadha. The epoch of *Vasiṣtha-siddhānta* is 3rd Dec. 499 A.D. although there existed another *Vasiṣtha-siddhānta* at the time of Sphujidhvaja (around A.D. 70). The *Vasiṣtha-siddhāntā* of *Pañcasiddhāntikā* belongs to a later version of the same under the name *Vasiṣtha-samāsa-siddhānta*. This was an abridged version of the same as is evident from its name.

The *Romaka-siddhānta* was commented upon by Lāṭadeva. The epoch adopted in this text is the Sun-set at Yavanapura (Alexandria) on 21st March A.D. 505. Its elements like the use of sun-set epoch, tropical year, Hipparchus' Metonic cycle, computational methods etc. indicate without any doubt its Hellenistic origin.

The *Pauliśa-siddhānta* has methodology of Babylonian and Greek astronomy with strong influence of Indian traditional concepts. There seems to be no way to sort out the original *Pauliśa-siddhānta*. The *Sūrya-siddhānta* of *Pañca-siddhāntikā* was compiled

by Lāṭadeva. He gave rules for computing *ahargaṇa* (number of days from an epoch) and methods of calculating solar eclipse etc. The system adopted here is the *ardharātrika* (mid-night system) of time reckoning and the epoch of this siddhānta is the midnight of Avanti 20/21st March 505 A.D. There is evidence of an earlier *Sūrya-siddhānta* which used somewhat different parameters for mean motions of the Moon, Rāhu (ascending node of the lunar orbit) and *candrocca* (lunar apogee)[13] etc. There is no doubt that the *Sūrya-siddhānta* was considered to be the most accurate. Its parameters were corrected and additions made in later centuries. The final version which we have today is much different from its version in *Pañca-siddhāntikā*. In fact, this belongs to the 9th or 10th century A.D. or even to a later date as is evident if one plots the errors in mean positions of planets against years over centuries.[14] A caution may be given in conclusions based on such methods as adopted by us and also in the ones adopted by David Pingree and others that it were the true positions and not mean ones which were observed and mean positions were fitted as *dhruvakas* (constant mean positions for the epoch) using the inequalities and the allied formulae adopted in those texts. Thus the mean positions computed by using modern accurate figures, even if these tally with the reports, may not prove the hypothesis concerning the epoch of the text. One should compute the true position ephemeride according to the texts in question, over centuries and also compute the ephemerides according to the most accurate data and inequalities of modern theories to get the true positions observable at those times. Wherever the two ephemerides give the best fit data observable, can be taken to be the epoch. Here allowance is to be made for observational errors or personal equations keeping in view the old observations to be the unaided eye records. Sometimes, a least square fit in data may also be necessary to eliminate the effects due to errors, and allowances for instrumental errors and the conditions under which those old observations were recorded are to be made.[15] Thus the epochs claimed on the basis of analytical computations using modern adopted figures only can not be taken with a grain of salt unless categorically mentioned in the text itself. Thus some of the claims, are to be rechecked and do not stand as a final verdict. Whatever the dates of these siddhāntas may be, these are earlier than 6th century A.D. or so (i.e. before Āryabhaṭa). Some of these may even go back to earlier dates.

Three Important Schools of Siddhāntic Astronomy

After the advent of siddhāntic astronomy (as evidenced from *Pañca-siddhāntikā*) three important siddhāntas (sometimes named as tantras) came into being over a period of about 500 years or so. These got into use in calendar making and in predicting astronomical phenomena throughout the country. These are *Āryabhaṭa-siddhānta* (due to Āryabhaṭa (A.D. 499)), *Brahma-siddhānta* (due to Brahmagupta), *Sūrya-siddhānta* (the latest version attributed to Asura Maya). These schools prevailed over centuries and are surviving even now in *Pañcāṅga* making (in preparation of religious Hindu calendars) in the country. There were teacher precept traditions in these schools which developed the formulations of the respective theoretical disciplines and went on advancing in theory keeping intact the basic constants and concepts of their respective schools. Many theoretical texts evolved in these traditions. These were

called 'siddhāntas' (theoretical treatises) while the texts giving only the simple algorithms (without proofs) for computing planetary positions, eclipses, cusps of the Moon, heliocentric rising and setting and other astronomical phenomena were called *Karaṇas* (means of practical work out of ephemerides and calendars). These were based on one or the other of the three schools of astronomy. It may be remarked that the school of *Sūrya-siddhānta* became the most widespread and is thought to be the most accurate of the three as it was improved and additions were made upto 10th century A.D. or even later. Earlier it was a Sāyana school (with spring equinox as zero longitude), but when the tropical *saṃkrāntis* (transits of Sun in tropical signs) showed much deviation with respect to the fixed zero of ecliptic, it accommodated the *ayanāṃśa* (angle of precession of equinox) given by Muñjāla. This siddhānta is even now used in northern, eastern and western parts of the country and also got accepted in neighbouring countries like Nepal, Burma, Tibet, Bhutan, Ceylon and also in far off countries, where Hindus and Buddhists made their way and settled. *Brahma-siddhānta* is used in some parts of Rajasthan and Madhya Pradesh and survives even now in somewhat reformed version due to an astronomer Caṇḍu (about 500 years ago) who prepared good tables for computing calendars. *Āryabhaṭa-siddhānta,* the oldest of the three is still in use in southern parts of India (in *Vākya karaṇas* which are the *karaṇas* based on simple algorithmic sentences *(vākyas)* making use of constants of *Āryabhaṭīya* tradition). It may be remarked that in later centuries, there evolved some other schools too with some variations in formulations, *bīja saṃskāras* etc., like Bhāskarācārya's etc. These had their own teacher-disciple tradition *(guru-śiṣya-paramparā)* over centuries, and got into use in calendar making and in computing astronomical phenomena, heliocentric rising, eclipses etc., but in general only the three schools prevailed. Here we discuss the siddhāntic texts of these three schools one by one in brief.

Āryabhaṭa-siddhānta

Āryabhaṭa prepared his epoch-making treatise *Āryabhaṭīya* (A.D. 499). There was another Āryabhaṭa II who wrote *Ārya-siddhānta*. Sometimes the *Āryabhaṭīya* is referred to as the first *Ārya-siddhānta*. It has mainly two parts[16] *Daśagītikā* and *Āryāṣṭaśata*. The first one has 10 *ślokas* in *Gīti* meter and deals with system of depicting numbers by symbols used for brevity in the body of the text and for the constants like *bhaganas* (number of revolutions of planets in a *kalpa*) etc. The length of solar year adopted in this text is 365 days 15 *ghaṭīs* 31 *palas* 15 *vipalas*. The number of *yugas* in a *kalpa* (Brahma's day) is 72 and not 71 as in other treatises. There are no *sandhis* after every beginning and end of a *manvantara* in this treatise.

The part after *Daśagītikā* consists of *Gaṇita-pāda, Kālakriyā-pāda* and *Gola-pāda.* The first one deals with pure mathematical formulae, on squares, cubes, roots, circles, algebra and indeterminate equations. The *Kālakriyā-pāda* discusses the units of time, conjunction of planets, *vyatīpāta* (equality of declinations), anomalistic and synodic periods, Jovian era, intercalary months, lord of day, mean position and equation of centre etc. *Gola-pāda* discusses armillary sphere, position of ecliptic, position of living beings on the earth, increase and decrease in the size of the earth in a *kalpa,* rotation of earth, vertical circle, rising of signs, eclipses etc.

This text is very brief. It does not discuss many topics as done in later treatises. For example, it is lacking in methods of computing cusps of the Moon, conjunction of planets, *tithis, nakṣatras, yogas* and *karaṇas* and does not give latitudes and longitudes of stars. There are no algorithms for computing heliocentric rising and setting of planets and conjunctions etc.

It is interesting to note that this treatise has given the notion of daily rotation of earth. Later astronomers like Brahmagupta and others have criticized this notion. Brahmagupta argues, how the birds can come home after full day flying in the skies? In Fact, Āryabhaṭa was ahead of his times in giving this idea of rotation of the earth. The earlier and later astronomers lingered on to the old concept of *Pravaha vāyu* (air) thought to be responsible for rotation of heavens once in a day.

Brāhma-sphuṭa-siddhānta

It was written by Brahmagupta (A.D. 628). The text[17] deals with mean and true positions of planets, problems of direction, time and space, lunar and solar eclipses, heliocentric rising and setting of planets, cusps of Moon, shadow of Moon, conjunctions of planets and stars, criticisms of other tantras (siddhāntas), arithmetic problems on mean and true positions, indeterminate equations, algebraic equations, gnomonics, permutation and combination in meters, celestial sphere, instruments and some algorithms for fast computations in *Dhyānagrahopadeśādhyāya.*[18]

In fact, the section on constructing meters *(chandas)* using permutation and combination is the obscure part of the text. It is not decodable because of grammatical mistakes and in copying over centuries, and also partly due to the inconsistencies in mathematical formulations arising because of these mistakes. It may be possible to decode it if one tries all possibilities of correcting versions grammatically and at the same time checking the versions thus corrected for mathematical consistencies. In al-Bīrūnī's *India* there is discussion on Brahmagupta's work on meters. The subject was not clear even to al-Bīrūnī at that time.

It may be noted that Brahmagupta did not believe in the precession of the equinoxes and criticized Viṣṇucandra who advocated the theory of precessional motion. So the *Brāhma-sphuṭa-Siddhānta* has tropical longitudes. In fact, at that time the angle of precession was quite small.

Brahmagupta wrote another treatise *Khaṇḍa-khādyaka.* In its first part, he has given constants like those in the *Āryabhaṭīya* and in the second part he has given corrections to improve upon the results from part I (which are just those of Āryabhaṭa) to make them tally with observations. This had to be done by Brahmagupta because *Ārya-siddhānta* had much popularity at that time and the scholars could not dispense with the methods of this work at least in Brahmagupta's time. Brahmagupta was a great critic. He criticized Āryabhaṭa's works on various astronomical topics especially on the computation of parallax for solar eclipses etc. Brahmagupta's work got much popularity and appreciation by the time of

Bhāskarācārya and even earlier. Al-Bīrūnī and Bhāskara held Brahmagupta in high esteem. There were written two *karaṇagranthas* based on *Brāhma-sphuṭa-siddhānta* upto Bhāskarācārya (A.D. 1150). In the 15th century Caṇḍu (as astronomer) prepared tables on the basis of this siddhānta which are still used in Rajasthan and Madhya Pradesh by some traditional *Pañcāṅga*-makers.

Sūrya-siddhānta

The third important school is that of *Sūrya-siddhānta*. The author is Mayāsura. As already pointed out it is much different from the *Sūrya-siddhānta* of *Pañca-siddhāntikā*. It has 14 chapters and deals with mean and true positions (on the basis of epicyclic theory) and problems of space, time and direction, lunar and solar eclipses, diagrammatical representation of eclipse phenomenon, conjunctions of planets and stars, polar longitudes and latitudes of stars, cusps of Moon, heliocentric rising and setting, instruments, geography, celestial sphere etc. The year-length adopted is 365 days 15 *ghaṭis* 31 *palas* and 30 *vipalas*. It allows only one equation of centre each for Sun and Moon and two equations of centre for other planets as in other treatises.

The text has reference to *ayanāṃśa* (angle of precession) while *Ārya-siddhānta* and *Brahma-siddhānta* did not use this at all. It may be remarked that in fact the relevant algorithms for computing *ayanāṃśa* were added to this text later. We have discussed this point in the section on *ayanāṃśa*. Muñjāla gave *ayanāṃśa* for the first time when it was about over 6½° or so. (Bhāskarācārya clarified this point that the same was given by Muñjāla). It was not at all noticed by scholars of the calibre of Brahmagupta and Āryabhaṭa, being small in their times. In fact before the introduction of *ayanāṃśa*, there might have been chaos in deciding the dates of *saṃkrāntis* (transits of Sun). Whatever be the situation at that time, the introduction of *ayanāṃśa* in *Sūrya-siddhānta* on the basis of Muñjāla's notion as expounded in *Laghumānasa*, proved to be a big shelter for the whole edifice of *nirayana* system of solar year reckoning and the astrology based on this system. Even though *ayanāṃśa* came into use, the year length was taken to be the same without any distinction between sidereal and tropical years over many centuries as the theory of trepidation of equinoxes got accepted in the algorithms for computing *ayanāṃśa* as given in *Sūrya-siddhānta*. This point is discussed in the section on *ayanāṃśa*.

This school got much popularity. Many *karaṇas* were written on the basis of this treatise, like *Grahalāghava*. *Makaranda-sāraṇī* etc., which were used for computing *pañcāṅgas* and astronomical phenomena over many centuries in all parts of India.

Besides these three siddhāntas, there were other treatises too, like *Mahābhāskarīya* of Bhāskara I (7th A.D.), Lalla's *Śiṣya-dhī-vṛddhida tantra*[19], Munjāla's *Laghumānasa* (A.D. 10th), *Siddhānta-śiromaṇi* of Bhāskarācārya II (A.D. 1150), *Siddhānta-sārvabhauma* of Munīśvara (early 17th century A.D.), *Siddhānta-tattva-viveka* of Kamalākara-Bhaṭṭa (A.D. 1656), *Siddhānta-darpaṇa* of Candrasekhara Samanta (19th century A.D.) of Orissa, etc.

Muñjāla's treatise is known for introducing *ayanāṃśa* in calendaric computations. This treatise *(Laghumānasa)* is also famous for giving an evection-like term in lunar theory which is a hybrid of evection and the first equation of centre. The amplitude of the evection term as given by him is quite correct. The texts like Munīśvara's *Siddhānta-sārvabhauma* and *Siddhānta-tattva-viveka* of Kamalākara too are based on *Sūrya-siddhānta*, but have their own advancements in the methods of computations and in developments of better formulae in various aspects of astronomical phenomena. The *Siddhānta-śiromaṇi* of Bhāskara II has unique features in the theory of indeterminate equations in advancing *kuṭṭaka-* (pulverizer) formulations, and also in 2nd degree indeterminate equations, especially in giving the advanced *cakravāla* -technique (1st given by Jayadeva). The theories of indeterminate equations were used by Bhāskarācārya in astronomical problems like in repetition of certain configurations of planets etc. Bhāskarācārya gave the detailed ideas about laws of gravitation of earth in his *Siddhānta-śiromaṇi*. He wrote a *karaṇagrantha* also under the name *Karaṇa-kutūhala*. He was also making constant efforts to improve the accuracy in the prediction of longitude of Moon and after having done daily observations of Moon over a long period, he wrote *Bījopanaya* (empirical corrections) giving sinusoidal empirical corrections to the longitude of Moon. The relevant formulae are just additive and subtractive constants varying with specific arguments. The arguments are these days realized on the basis of perturbation theory, but due to intermixing of many sinusoidal functions and lack of Fourier-like analysis his attempts did not result in clear cut identification of fortnightly variation, annual variation and evection functions. In fact, Bhāskara missed evection, as he observed Moon in specific positions where the same was zero, and he did not use the same on the mere authority of Muñjāla. This resulted in the failure of the analysis.[20] Candrasekhara Samanta of Orissa (19th A.D.) was an orthodox scholar of Indian astronomy. Samanta was not at all acquainted with the developments in the west. He devised some instruments and determined lunar inequalities independently. He gave annual variation for the longitude of Moon.[21]

In the seventeenth century A.D. Paṇḍita Jagannātha Samrāṭ under the patronage of Jai Singh Sawai wrote down *Samrāṭ Siddhānta* and translated the *Almagest* of Ptolemy in Sanskrit under the name *Siddhānta Samrāṭ*[22]. It has 13 chapters and 140 sections with 196 diagrams. Jai Singh Sawai with the help of Pt. Jagannātha could erect five observatories. It may be remarked that in the works of Jai Singh Sawai and Paṇḍita Jagannātha the lunar theory advanced more eccentric corrections and better constants for amplitudes were formulated. Jai Singh Sawai's tables *(zij)* for computations of Sun, Moon, planets and *pañcāṅgas* deserve special attention. The tables like *Vedhopayogi Sāraṇis* (tables yielding observable positions for Moon etc.) are preserved in the library of his observatory in Jaipur. On analysis, the tables can furnish lot of information about developments in lunar theory and Sun's equations of centre, etc.

KARAṆAGRANTHAS AND SĀRAṆIS

Siddhāntic texts are theoretical treatises which give formulae with their proofs or explanations for computing ephemerides, *pañcāṅgas* and astronomical phenomena.

In these computations they use very big numbers as their epoch is usually the day of beginning of creation (according to the treatise) or Brahmā's day. The number of days elapsed since the date of creation is a very large figure (much larger than the Julian day number). The velocities of planets, nodes and apogees etc. too are given over a *Kalpa* (Brahmā's day, usually 432×10^7 years). Thus, it is clear that the figures involved in computations, using siddhāntic formulae, are very big and this renders the calculations very much cumbersome. The followers of the siddhāntic schools, although adhering to the basic constants of the treatise of their respective schools, wanted to simplify the computations and moreover, for actual operations, they needed ready-made formulae to fasten their calculations. This need gave rise to *karaṇa-granthas* which were intended to facilitate the calculations. Usually these have the following salient features :

(1) Unlike siddhāntic texts, these use *laghu ahargaṇa* (smaller number of days) from the epoch of compilation of the *karaṇa*. For the beginning date of the epoch, they provide the mean positions of planets and orbital elements and mean *tithis, nakṣatras* etc. (called *dhruvakas*) in tabulated forms. For computing the functions on any later (or earlier) day, the velocities of functions (planetary velocities in computation of their longitudes) are given. These are called *kṣepakas*. Usually these are given over a convenient cycle of 18 years or 19 years etc., or even over one year in which case the yearly *dhruvakas* are computed on the beginning day of every year. The *Grahalāghava* uses 14 years cycle with 444 śaka era epoch. For computing every day planetary ephemerides, *tithis, nakṣatras* etc. the daily speeds of the functions are used. For example, in computing daily *pañcāṅga* elements, the daily mean velocities of *tithis, nakṣatras* etc. are used and then corrections due to equations of centre are applied. The Makaranda tables use such techniques for computing *pañcāṅga* elements, making use of mean motions of Sun and Moon and the equations of centres of the *Sūrya-siddhānta* school.

(2) In order to provide convenient formulae in algorithmic form without going into the details of the proofs, etc. these use approximations in reducing formulae to simplest possible form without much loss of accuracy in approximations. For example, a bigger fraction may be reduced to simple form using continued fractions and terminating them at an appropriate stage. Sometimes, these are reduced to partial fractions to provide simple fractions with single denominators and fractions thereof, as additives or subtractives. Such techniques are used by Gaṇeśa Daivajña in his *Grahalāghava*. Sometimes even the sine functions are dispensed with under some approximations. *Grahalāghava* stands at the top in such treatments. Surprisingly enough its author did not use trigonometric functions as such, but gave the inequalities as additives or subtractives, after every (specific convenient) intervals for which simple ratio proportional interpolation is possible.

(3) Sometimes, *karaṇas* use empirical corrections in mean functions in order to have their results tallying with observations (no doubt the basic constants of the siddhāntic texts were retained as such). *Rājamṛgāṅka, Makaranda* and *Grahalāghava* applied empirical corrections in positions of planets but in none of the *karaṇas* any

empirical correction was applied to the longitude of the Sun. It is only the *karaṇas* of the 20th century like *Mārāṭhī grahagaṇitam* etc. by V. B. Ketakara which used corrected mean elements for Sun.

(4) Siddhāntic texts usually do not provide tables for computations (except some trigonometric functions etc. tabulated in some cases). On the contrary, *karaṇas* or *sāraṇis* try to provide necessary tables for quick computations. The *sāraṇis* have required elements tabulated against respective arguments. All the theoretical computations are already done in preparing the tables and for the user, only some simple arithmetic is left to get the final results.

Some Karaṇagranthas Based on Three Principal Siddhāntas

The Vedic and Vedāṅga astronomy made use of five-year *yuga* system. Even in the *Pañca-siddhāntikā,* we find *yugas* of small spans only. Moreover, the algorithms used in pre-siddhāntic astronomy were very simple. So no need was felt for preparing *karaṇa-granthas* in those times. It is only after the advent of siddhāntic astronomy by Āryabhaṭa that need was felt to prepare *karaṇa-granthas* in order to avoid big figures, arising from the use of *mahāyuga, kalpa* etc. in *ahargaṇa.* We do not have records of early *karaṇa-granthas.* But in the case of the *Brāhmasphuṭa-siddhānta,* we find two *karaṇas*[23] even before Bhāskarācārya. One of them used no empirical corrections in the results from *Brahma-siddhānta,* while second one, Rājamṛgāṅka by Bhoja, used *bīja* corrections in order to rectify the errors in mean positions accumulated over centuries. As mentioned earlier, astronomer Caṇḍu (16th century A.D.) prepared *sāraṇis* which are still being used by some *pañcāṅga* makers. Bhāskarācārya wrote a *karaṇa* text *Karaṇa-kutūhala* based on the constants of his treatise and wrote a separate booklet on sinusoidal empirical corrections in order to rectify the position of Moon. It may be remarked that the empirical correction (except in mean positions in some cases) were not approved for siddhāntas because in these theoretical texts only the corrections which had mathematical justification were allowed. So, in general, empirical corrections (specially sinusoidally varying *bīja* corrections) were not used in *siddhāntas.* The *karaṇas* used the corrections as temporary improvements for getting results tallying with observations. There are available *karaṇas* based on *Ārya-siddhānta* too, like *Vākya-karaṇa* by Sundara Rāja[24] of Southern India. There is another *karaṇa-grantha, Cāru-Candra Vākyāni* which is used for getting longitude of Moon. These *karaṇas* are based on *Āryabhaṭa-siddhānta* and give simple sentences which help in fast computations. The simple algorithms are put in simple sentences (*vākyas,* that is why the name *vākya-karaṇas*) which are very easy to remember. Sometimes, the sentences are very interesting having two meanings—astronomical and cultural.[25] It may be remarked that these texts have corrections to the position of Moon which are hybrids of lunar inequalities.[26] These *vākya-karaṇas* are used in preparing *pañcāṅga* in southern part of India.

There are many *karaṇa-granthas* based on the *Sūrya-siddhānta.* The *Graha-lāghava* of Gaṇeśa Daivajña (1522 A.D.) is famous among all these because of its simple algorithms and much simplified versions of complicated formulae. As already pointed

out it has avoided the use of trigonometric functions as such and provided the elements at certain intervals of their arguments, which work quite well yielding satisfactory results. Gaṇeśa Daivajña himself has cautioned that in future his algorithms might give wrong results due to accumulation of errors with the lapse of time; in that case corrections should be applied after having verified the results with the help of instruments and thereby changing the arguments of the functions in accordance with observations. There are tables based on the *Sūrya-siddhānta* too. Makaranda's tables (A.D. 1478) are used for computing *pañcāṅga* elements and were popular for over 3 centuries or so. These tables too have applied *bija* corrections in planetary positions, except in the case of the Sun. Besides these there are many other *karaṇa-granthas* based on *Sūrya-siddhānta*. The earliest one is *Karaṇatilaka* of Vijayanandi.[27] That of Babilal Kochanna (A.D. 1298), *Bhaṭatulya karaṇa* (A.D. 1417), *Sūryatulya karaṇa* (A.D. 1523), *Grahakautuka-karaṇa* (A.D. 1496), *Bhāsvati-karaṇa* (A.D. 1520) and many more were written in later centuries.

This tradition of preparing *karaṇa-granthas* and tables was upheld by Kero Lakṣmaṇa Chhatre (19th century A.D.) and later astronomers of Indian tradition. Chhatre prepared tables for computing planetary positions using modern data. V. B. Ketakara prepared *Jyotirgaṇitam* (1898 A.D.), an epoch-making *karaṇa* type work with many tables provided for easy computations and used modern formulae based on gravitational perturbation theory. In the last half of 19th century a number of people rectified *pañcāṅga* elements by applying eccentric inequalities in case of Sun and Moon. Ketakara also wrote *Mārāṭhi grahagaṇitam* which provided many tables for calculations of *pañcāṅga* elements and planetary positions. Also there is *Ketakī grahagaṇitam* by V. B. Ketakara written in the style of *Graha-lāghava*.

In recent years too, there are *karaṇagranthas* produced by some scholars, e.g. *Karaṇa-kalpalatā* by K. L. Daftari (1976) and *Sarvānanda-lāghavam* by G. S. Apte. G. S. Apte wrote also another *karaṇa Sarvānanda karaṇa* again in the style of *Grahalāghava*, just improving the latter to get results tallying with observation. This text adopted *Sāyana* system of planetary longitudes. There are also tables prepared by various almanac makers like *Vṛhat-siddha-kheṭī* by Raja Ram Sharma. Besides these we find scattered materials like tables of *nakṣatras* of unequal spans as stated by Bhāskara. Also there are tables for computing *lagnas* (ascendants) etc. There is another text *Grahamālā* which can yield rough planetary positions and their retrogradations rising and setting etc. for any past or future years. These are ready reckoner tables based on bigger cycles of planets with respect to the Sun. Thus a prodigious amount of literature in various aspects of astronomy in Indian tradition was produced even in the present century.

6 THE YUGA SYSTEM AND THE COMPUTATIONS OF MEAN AND TRUE PLANETARY LONGITUDES

D. ARKA SOMAYAJI

THE YUGA SYSTEM

INTRODUCTION

We find the mention of the *Yuga* system not only in the Indian astronomical works but also in the Paurāṇic literature. It is now difficult to trace whether the astronomical works of India borrowed the *Yuga*-concept from the *Purāṇās,* or whether the latter from the former. We shall first note the details of the *Yuga*-system, as is now in vogue, in the light of the information given in the most important astronomical works. (It may be mentioned that this word *yuga* appears even in many places in the *Ṛgveda* (Vide 1-158-6).

We are told that we are now in *Kaliyuga* which began at the mid-night of Laṅkā, between the 17th and 18th February 3102 B.C. The duration of this *Kaliyuga* is given to be 432,000 solar years. *Dvāpara yuga* which preceded this *Kaliyuga,* is reported to have the duration of two *Kaliyugas.* The *Tretā-yuga,* which preceded the *Dvāpara* was equal to three *Kaliyugas* in duration and the *Kṛta-yuga,* otherwise called *Satyayuga,* which preceded the *Tretā,* was equal to four *Kaliyugas* in duration. These four *yugas, Kṛta, Tretā, Dvāpara* and *Kali,* are often called *Yuga-pādas,* or the quarters of their sum, called *yuga,* otherwise called *Mahāyuga.* Thus a *Mahāyuga* is equal to $4+3+2+1=10$ *Kaliyugas* in duration$=$4320,000 solar years. *Sūrya-siddhānta* uses the word *yuga* for *Mahāyuga*[1]. The same *Sūrya-siddhānta* says in another breath, "*asmin kṛtayugasyānta sarve madhyagatāḥ grahāḥ*"[2] thus speaking *Kṛta* again as *yuga.* Let us call these *Kṛta* etc., as *yugas,* and the sum of the four namely *Kṛta, Tretā, Dvāpara* and *Kali* as a *Mahāyuga* to avoid equivocation. Then a *Mahāyuga* consists of 43,20,000 solar years. Seventyone *Mahāyugas* are reported to constitute a *Manvantara* or duration of a Manu's reign. Fourteen *Manvantaras* constitute what is called a Kalpa. *Sūrya-siddhānta* says: "A *Kalpa* is the day-time of a day of Brahmā, the Creator, and the night is also of the same duration."[3] The Cosmic manifestation is reported to last during the day-time, and to be withdrawn or annihilated during the night time.

Further, we are told that there will be what are called, *Sandhyās* in between two *Manvantaras* each equal to a *Kṛta Yuga* in duration, which is equal to four Kaliyugas or $\frac{4}{10}$, i.e. $\frac{2}{5}$ of a *Mahāyuga.* Since there will be fifteen such *Sandhyās* among the fourteen *Manvantaras,* the duration of these fifteen *Sandhyās* put together is equal to $15\times\frac{2}{5}=6$ *Mahāyugās.*

Thus a Kalpa is equal to $14 \times 71 + 6 = 1000$ *Mahāyugas* $= 4{,}320{,}000{,}000$ solar years.

Before we go into the rationale of all this, it is better to know the other nomenclature used in this context. The *Sūrya-siddhānta* speaks of what is called a *Divyābda*, or an year of the gods of the heavens equal to 360 of our solar years, our one year equalling a day of theirs. It is interesting to note that Hindu mythology reports that gods (By 'gods' it should not be misinterpreted that the Hindus were that primitive as to postulate the existence of many gods. As per Hindu philosophy, there is the godhead, a supreme supernal Consciousness or Intelligence otherwise called Brahman, which is the architect of this universe. This Brahman, (note that it is in neuter gender), while creating is called Brahmā (masculine gender), while sustaining the universe Viṣṇu, and while annihilating the universe Rudrā. Though this Godhead, i.e. the Brahman is one, we are told that there is a hierarchy of Gods, inferior to this Brahman, besides such celestial species like Gandharvas, Kinnaras, Kimpuruṣas etc., all of whom may be deemed to correspond to the so-called angels spoken of in the English literature. These gods are reported to reside on the Meru mount, which we may identify as the north-pole. There, we have a perpetual day equal to six-months and a perpetual night equal to six months, so that one day there is equal to one year. The word *Surālaya* which is a synonym of the *Meru* means that it is the abode of such gods.

Thus, one year of ours, equalling one day of those gods, 360 years of men constitute an year of gods, which is the reason why they are called *Divyābdas*, or years of gods. We cannot help here going into the Hindu mythology, to expound the *Yuga*-system, though ultimately the *Yuga*-system is astronomical in concept. A mention is made of this *Divyābda* because *Sūrya-siddhānta* has used it. Incidentally, it may be mentioned here, that a day on the Moon is roughly equal to a lunation, otherwise called *Cāndramāsa*. We are told that for the Manes, who are reported to reside on the Moon, a lunation of men is equal to a day. This is all by the bye.

Here and now, it may be mentioned that as per Āryabhaṭa, Lalla, and Vaṭeśvara, who are reported to constitute the Keral school of astronomers, the four *Yuga-pādas* namely *Kṛta, Tretā, Dvāpara* and *Kali* are of equal duration. This is a reason why Brahmagupta criticized Āryabhaṭa for having said so, against the canons of *Smṛtis*. Indeed there seem to have been two schools of astronomy in ancient India, the first consisting of Brahmagupta, Śrīpati and Bhāskara etc., and the other Āryabhaṭa, Lalla, Vaṭeśvara and others. *Sūrya-siddhānta* belongs to the former school, the name of the author not being known as against the orthodox tradition, which claims that a deputy of the Sun taught Maya this siddhānta at the end of the *Kṛta Yuga*. There is another Āryabhaṭa, who may be termed Āryabhaṭa-II, who was the author of one *Mahā-siddhānta*. M. M. Sudhākara Dwivedi makes out that the author of the *Sūrya-siddhānta* lived between Āryabhaṭa-I and Āryabhaṭa-II. Incidentally, it may be mentioned that there was also Bhāskara-I who wrote a commentary on the work of Āryabhaṭa-I.

The rationale behind the statement that 71 *Mahāyugas* constitute a *Manvantara* is not traceable. The number 71 is indeed a peculiar number. At present, we are told that we are under what is called *Śveta Varāhakalpa.* Therein, six *Manvantaras* had elapsed and we are now under what is termed the duration of *Vaivasvata Manvantara.* In this *Manvantara,* twenty-seven *Mahāyugas* lapsed away and we are now under the 28th *Mahāyuga.* The three *Yugas—Kṛta, Tretā* and *Dvāpara* also lapsed away. Under the present *Kaliyuga,* 5083 years lapsed by 26-3-1982 as per the *Cāndra Māna* reckoning, and by 14-4-1982 as per the *Saura-Māna* reckoning.

Bhāskara (hereafter Bhāskara means Bhāskara-II) says that 1,97,29,47,179 years had elapsed by the beginning of the Śālivāhana Śaka, the Zero point of time as per the siddhānta calculations which occurred after the lapse of 3179 years from the beginning of this *Kaliyuga,* as per the details cited above. Here it must be pointed out that, whereas the *Sūrya-siddhānta* mentions that creation of the stars, planets began after the lapse of 47400 *Divyābdas* or 47400 × 360 years, after the beginning of the Kalpa, Brahmagupta, Śrīpati and Bhāskara mention that creation started from the beginning of the Kalpa.

Bhāskara quotes the *Sūrya-siddhānta* saying that the equinoctial points precede at the rate of 30,000 in a Kalpa. Inasmuch as this rate comes to 9″ per year, which is far less than 50″, the approximate rate of precession, and inasmuch as the *Sūrya-siddhānta* which was incorporated by Varāhamihira in his *Pañcasiddhāntikā* does not mention precession at all, it must be deemed that Bhāskara had the present *Sūrya-siddhānta* in his hands but read only the verse *Triṃśat-Kṛtvo yuge bhānām cakram prāk parilambate.* This indicates that the latter verses in this context, which make out that the rate of precession per year was 54″, postulating the libration theory (i.e. the theory that the equinoctial points do not precess secularly, but oscillate about the zero-point of the zodiac, i.e. the begining of Aśvinī to an amplitude of 27° on either side) were interpolated.

Brahmagupta was a great mathematician, whom therefore two great astronomers Śrīpati and Bhāskara followed. These three were mathematically rational astronomers. The very fact that, when the *Sūrya-siddhānta* was already extant in the times of Śrīpati and Bhāskara, they still chose to write fresh works of their own, signifies that the *Sūrya-siddhānta* did not enjoy the same popularity among the orthodox Hindus, as it enjoys now. This is really curious.

Rationale of the Yuga System

Before reading into the rationale of the *Yuga*-System we have got to look at the data given by the various astronomers with respect to the number of sidereal revolutions of the planets in a Kalpa etc. The following tables give those data, in addition to the modern data taken from Ball's *Spherical Astronomy.*

Table 6.1. *Number of sidereal revolutions of planets and planetary points in a Kalpa*

	Modern *Sūrya Siddhānta*	Bhāskara	Āryabhaṭa	*Khaṇḍa Khādyaka*	*Mahā-siddhānta*
Sun	4320000000	4320000000	4320000000	4320000000	4320000000
Moon	57753336000	57753300000	57753336000	57753336999	57753334000
Mars	2296832000	2296828522	2296824000	2296824000	2296831000
Mercury	17937060000	17936998984	1793702000	17937000000	17937054671
Jupiter	364220000	364226455	364224000	364220000	364219682
Venus	7022376000	7022389492	7022388000	7022388000	7022371432
Saturn	146568000	146567298	146564000	146564000	146569000
Moon's Apogee	488203000	488205858	488219000	488219000	488208674
Moon's Node	232238000	232311168	232116000	232226000	232313354

Table 6.2. *Number of mean solar days, lunar days, omitted lunar days, diurnal revolutions of stars etc. in a Kalpa*

	According to *Sūrya Siddhānta*	According to Bhāskara
(a) Number of mean solar days in a *Kalpa*	157791728000	1577916450000
(b) Number of *Adhikamāsas* in a *Kalpa*	1593336000	1593300000
(c) Number of *kṣayāhas* in a *Kalpa*	25082252000	25082550000
(d) Diurnal revolutions of stars	1582237828000	1582236450000
(e) *Tithis* in a *Kalpa*	1603000080000	1602999000000

Table 6.3. *Daily mean motions of planets*

	Brahmagupta Śrīpati and Bhāskara
Sun	0-59′-8″-10‴-21⁗
Moon	13°-10-34-53-0
Mars	0-31-26-28-7
Mercury	4°5′-32″-18-28
Jupiter	0-4-59-9-9
Venus	1-36-7-44-35
Saturn	0-2-0-22-51
Moon's Apogee	0-6-40-53-56
Moon's Node	0-3-10-48-20

Table 6.4. *Elements of the Solar System. Epoch* 1900 (*from Ball's Astronomy*)

Name of Planet	Semi. Major Axis of Orbit =Unity	*Sidereal Period* Mean Solar Day	Mean Daily Motion	Longitude of Perihelion	Longitude of Ascending Node	Inclination of Orbit	Eccentricity
Mercuty	0.3870986	87.96926	4°5′32″.4	75°53′59″	47°8′45″	7°0′10″	0.205614
Venus	0.7233315	224.7008	1 36 7.7	130 9 50	75 46 47	3 23 37	0.006821
Earth	1.000000	365.2564	59 8.2	101 13 15	8 0 0	0 0 0	0.016751
Mars	1.523688	686.9797	31 26.5	334 13 7	48 47 9	1 51 1	0.093309
The Asteroids							
Jupiter	5.202803	4332.588	4 59.1	12 36 20	99 26 42	1 18 42	0.048254
Saturn	9.538844	10759.20	2 0.5	90 48 32	112 47 12	2 29 39	0.056061

We see a good divergence with respect to the sidereal revolutions and some other items, pertinent to our context. Why was there such difference, we have got to investigate. The argument may be given as follows.

The ancient Hindu astronomers could find the mean motions of the planets with sufficient accuracy though they did not have the modern instruments like the telescope etc. But one point must be clearly noted. *Knowing those mean daily motions, and the positions of those planets at their respective times, each of the great astronomers calculated back, as to when all the planets should have been at the Hindu zero point of the ecliptic.* It may be mentioned here, that the Hindu zero-point of the ecliptic is not the position of the equinoctial point, but the beginning point of the asterism Aświnī, which is now identified as ξ Piscium. Ranganatha (birth date about A.D. 1573) a commentator of the *Sūrya-siddhānta* said that the zero-point of the ecliptic was 10′ behind this ξ Piscium. Other astronomers did not specify where it was, probably because it was popularly known in their times. Unfortunately we are not in a position now to know which was exactly their zero-point.

The present-day Hindu astronomers are of two kinds : (1) those who are competent to teach the major texts like *Āryabhaṭīya*, *Sūrya-siddhānta* and *Siddhānta-śiromaṇi* of Bhāskara, with proofs; and (2) those who compute *pañcāṅgas* only basing on works called *karaṇa-granthas*. Those *karaṇa-granthas* are manuals which simplify the siddhāntas and give easier procedures to compute the planetary positions taking the starting point not from the beginning of the Kalpa nor even from the beginning of the *Kaliyuga*, as prescribed by the *Siddhāntas*, but from their recent epochs, which facilitated computation. It is unfortunate that neither of these categories of scholars namely those who teach the siddhānta texts, nor those who compute *pañcāṅgas* today are in the habit of observing the planetary positions. The second category of

pañcāṅga-computers, whose number is thousand-fold the number of the former category, are ignorant of the rationale of the siddhāntas. They learn just the method of computation only. This is why Hindu astronomy fell long ago on evil days, creative activity having been already defunct. This is by the bye.

Śrīpati and Bhāskara took their data regarding the sidereal revolutions of planets etc. from Brahmagupta. Brahmagupta says—*Brahmoktam grahagaṇitam mahatā kālena khilībhūtam abhidhīyate shutam tat jiṣṇusuta brahmaguptena,* i.e. inasmuch as the ancient *Brahma Siddhānta* got obsolete; I am now rectifying it. Siddhāntas are prone to grow obsolete because of two important reasons: (1) the presumption that at the beginning of Kalpa all the planets with their aphelia and nodes were situated at the Hindu zero-point of the ecliptic; and (2) the mean daily motions as taken by the siddhāntas could not be expected to be as accurate as it should be. On these two counts it was but natural that the computed positions of the planets could not accord with their observed positions. Hence new siddhānta came to be written, which gave results which held good at their times. But again, these were bound to grow obsolete because of the same two reasons cited above.

In this context, one point must be stated. The Hindu astronomical texts construed that the Sun, Moon, Rāhu and Ketu, the latter two being the nodes of lunar orbit are also planets along with the five planets Mercury, Venus, Mars, Jupiter and Saturn. These latter five are of course planets as per modern astronomy, whereas calling the Sun, Moon, Rāhu and Ketu as planets may sound odd to modern astronomers. But what the Hindu astronomers meant by the word *grahas* (now talked of as planets) was that the Sun, Moon Rāhu and Ketu also had astrological influence on the fates of men as per the etymological significance of the word *graha.* The planets Uranus, Neptune and Pluto not observable by the naked eye came to be discovered during recent times and as such did not receive mention in the Hindu astronomical texts.

Now let us seek the rationale of the *yuga* system. It is easy to see that a Kalpa is the period in which all the planets, with their nodes and aphelia, make an integral number of revolutions with respect to the stars. This period was therefore computed, by the Hindu astronomers, noting their mean daily motions, and their positions at a particular time. It was therefore an extrapolation. We can take it that Brahmagupta who was indeed a great mathematician did this extrapolation. Śrīpati and Bhāskara indeed quote his name with reverence in the words—*Kṛtī jayati jiṣṇujo gaṇakacakra-cūḍāmaṇiḥ*—i.e. "Brahmagupta excels, as the head-worn gem of all astronomers." So also does Śrīpati praise him[4] prior to Brahmagupta. We can take it that Āryabhaṭa also did that extrapolation.

In this context, the question arises, as to how the ancient Hindu astronomers were able to get the period of a sidereal revolution of Saturn, to a tolerable accuracy, inasmuch as one sidereal revolution of Saturn is nearly 29½ years. The doubt may arise because, to obtain the duration of one sidereal revolution, many of such revolu-

tions must have been observed. This doubt need not be there, because the ancient Hindu astronomers knew the formala $\frac{1}{Y}-\frac{1}{P}=\frac{1}{S}$ though not in this form, where Y stands for the length of an year, P for the duration of the planet's sidereal revolution, and S for the synodic period of that planet all in mean solar days. Since Y and S which are small periods, could be observed accurately P could be calculated to a good amount of accuracy.

Y, i.e. the number of mean solar days in solar year could be observed accurately as follows as was mentioned first by Āryabhaṭa and later by Bhāskara. We are directed to erect a vertical *śaṅku*, i.e. a gnomon on a plane. This *śaṅku* is divided into twelve equal parts called *aṅgulas*. Draw a circle with a radius equal to the length of the *śaṅku;* draw the east-west line through the foot of the *śaṅku*. Bhāskara gives the method of drawing this east-west line correctly, which was primarily given by one Caturvedācārya, a commentator of *Khaṇḍa-khādyaka,* and later reiterated by Śrīpati who preceded Bhāskara. This *Khaṇḍa-khādyaka* is reported to be written by Brahmagupta, but this report is subject to doubt because Brahmagupta criticized Āryabhaṭa right and left and the interpretation given by M. M. Sudhākara Dvivedi that though Brahmagupta happened to criticize Āryabhaṭa in his *Brāhmasphuṭa-siddhānta,* changed his mind later on account of the overwhelming popularity of Āryabhaṭa, and as such chose to write a manual to accord with *Āryabhaṭīyam*. On close examination of the data of *Brāhma-sphuṭa-siddhānta* and *Khaṇḍakhādyaka,* it will be found that some body wrote this *Khaṇḍakhādyaka* and foisted it on Brahmagupta to enhance the credit of Āryabhaṭa.

To draw the east-west line, we are asked to note the point in the morning on the circumference of the circle drawn with the foot on the gnomon as centre, when the shadow of the gnomon equals the radius of that circle. Again we are asked to mark the point on the circumference in the afternoon, when the shadow equals the radius of the circle. The line drawn parallel to the joint of these two points through the foot of the gnomon is the rough east-west line. It is rough because, the declination of the Sun will have changed in between the two points of observation. A correction was prescribed to rectify this, which goes by the name *agrāntara* correction. The amount of correction is given to be

$$\frac{K \triangle (\sin \delta)}{\cos \phi} \text{ } \textit{aṅgulas},$$

where $\triangle$ $(\sin \delta)$ is the variation of the sine of the declination of the Sun between the two moments. K is equal to $\sqrt{12^2+s^2}$ where s is the length of the shadow, and ϕ is the latitude of the place.[5] We are asked to shift the point pertaining to the afternoon observation on the circumference, when the shadow equals the radius of the circle towards that direction in which the Sun is having motion in declination, i.e. towards north between December 23rd and June 22nd and south between June 22nd and December 23rd.

Now we are asked to note the point roughly about December 23rd, when the Sun's declination equals the obliquity of the ecliptic. It may happen in between two days and the fraction of a day can be roughly obtained. After one year lapses away, again, the point is to be noted about 23rd December. The interval in between these two points of time is the length of a solar year (of course tropical). Observations were carried for a number of years like that and their average gave the actual length of the year. Hindu astronomers took the obliquity to be 24°. Now it is 23°27′. At Brahmagupta's time it should have been greater than 23°30′ since this obliquity has been decreasing. It is noteworthy, that the Hindu mean solar year is just 3.25 minutes of time more than the value given by modern astronomy. The length of a lunation, on the other hand, was computed by noting the time in between two lunar or solar eclipses and dividing that interval by the number of lunations in between. Thus it is also noteworthy that the length of a lunation was also obtained to a great nicety indeed. Since the formula $\frac{1}{P} - \frac{1}{Y} = \frac{1}{S}$ was known to the Hindu astronomers, where P is the length of the sidereal month and S the length of a lunation, P could be obtained very accurately. It was possible to obtain the value of P also by direct observation, so that striking an average it was possible to get the values of P and S very accurately with respect to the Moon.

Similarly noting the intervals between two heliacal settings or risings of planets, and also by direct observation the sidereal periods of Mercury, Venus, and Mars could be obtained. With respect to Jupiter and Saturn alone, whose sidereal periods are far greater, their synodic periods, i.e. the interval between two heliacal risings or settings gave a correct value of the sidereal periods using the formula

$$\frac{1}{Y} - \frac{1}{P} = \frac{1}{S}.$$

Having thus obtained the sidereal periods of all the planets with sufficient accuracy, their L.C.M., so to say, was computed to obtain the period in which an integral number of sidereal revolutions were contained. In the first place, Āryabhaṭa obtained the L.C.M, i.e. the period in which all the planets made an integral number of revolutions as the *Mahāyuga* equal to 4,320,000 years. Thereafter Brahmagupta obtained the period of a Kalpa as that period in which Sun, Moon, Mars, Mercury, Jupiter Venus, Saturn, Moon's apogee, and Moon's node made an integral number of revolutions, thus effecting a change in the number of sidereal revolutions as given by Āryabhaṭa. It is easy to see that Brahmagupta effected this change because, the planetary positions computed did not accord with the observed positions. It was after all a period of one hundred years in between Āryabhaṭa's date of composition namely 499 A.D. and that of Brahmagupta's date of composition 598 A.D. The small divergences perceived between the computed positions and observed positions made Brahmagupta seek the larger period of a *Kalpa* in which the planets made an integral number of revolutions. He computed this period of *Kalpa* and changed the numbers of sidereal revolutions so as to effect accordance between the computed and observed

positions at this time. But, it will be noted that the fundamental presumption that the planets must have started at the Hindu Zero-point of the zodiac either in the beginning of a *Mahāyuga* as thought by Āryabhaṭa or at the beginning of the *Kalpa* as construed by Brahmagupta is open to doubt. In the light of modern astronomical data, this presumption stands questioned.*

In conclusion, on account of such a presumption as cited above, as well as a little roughness which could not but be there (on account of lack of instruments which we have today) in the lengths of the sidereal periods of the planets, Hindu astronomers went on moving in a vicious circle, writing new texts to effect accordance between the computed and observed positions. However, we cannot but give them the credit due to them for having persevered diligently for centuries and centuries keeping up the light burning. This creative activity went on upto the time Kṛṣṇa Daivajña who is reported to be born in 1565 A.D. as per M. M. Sudhākara Dvivedi, and who was the court pandit of Jahangir. This great mathematician gave us the *muhūrta* prescribed by him for the coronation of Shahajahan. He wrote a commentary on Bhāskara's *Bījagaṇita* under the caption *Navāṅkura* which exhibits his genius. At the end of the commentary, he wrote a verse which means "Oh! God! Thou alone knowest what stress and strain I have undergone in writing this commentary on Bhāskara's *Bījagaṇita*. Hence I dedicate this to thee alone and to no mortal, however great he may be."

COMPUTATION OF MEAN LONGITUDES OF THE PLANETS

Ancient Hindu astronomers (for example Bhāskara) gave the mean positions of the planets at the beginning of the Kaliyuga at the mid-night between 17th and 18th february 3102 B.C. or at the sunrise on 18th February, which held good for the Laṅkā meridian. This Laṅkā, reported to be the capital of Rāvaṇa is situated on the terrestrial equator. This Laṅkā meridian was taken to be the primary meridian by the Hindu astronomers and was termed *bhūmadhyarekhā*. Nowadays, it is to be noted that this word *bhū-madhyā-rekhā* is applied to the terrestrial equator. In Hindu astronomy the name for the equator is *nirakṣa rekhā*, i.e. the line on which the *akṣa* or latitude is zero. The Laṅkā meridian is reported by Bhāskara to be passing through Ujjain, Kurukṣetra and the north-pole[6]. Ujjain has been famous from times immemorial (Kālidāsa describes this Ujjain in his famous kāvya *Meghasandeśa*). It lies on the meridian 75° east of Greenwich. The latitude and longitude of Laṅkā are therefore 0°, 75° respectively. Since this spot is now deep in the Indian ocean, it is not possible to know, whether this is a mythological or imaginary place or whether the ocean was not there in the distant past (geology says that the ocean also has changing beds). Even today, it is noteworthy that the *pañcāṅga*-computers calculate the mean positions of the planets for this Laṅkā-meridian and thereafter effect the correction called *deśāntara* to obtain the mean positions for their respective places on any day. The *Sūrya-siddhānta* also directs us to calculate the mean positions first for Laṅkā

* However, it may be added that if Jean's theory about the formation of the planetary system were correct, all the planets should have been in a line at the time of their formation.

at midnight.[7] It also says that the week-day begins at the mid-night of this Laṅkā-meridian.[8] Āryabhaṭa, however, directed that the mean longitudes be computed either for the midnight or for the Sun-rise at Laṅkā. On this count, Brahmagupta criticized Āryabhaṭa for giving two systems.

Since computations of the mean planetary positions taking their data at the beginning of the *Kaliyuga,* is very laborious, later on *karaṇa-granthas* came to be written, which may be called manuals for the purpose of easy computation, giving us the mean positions at their respective days. Astronomical treatises which prescribe computation from the beginning of the *Kalpa,* the extrapolated date, when all the planets, their orbital nodes and aphelia all were supposed to have zero longitude are called *siddhāntas;* those which prescribe computation from the beginning of *Kaliyuga* are called *tantras,* whereas those works of recent origin (these are hundred-fold in number) which prescribe computation from their recent respective dates are known as *karaṇa granthas*. The *karaṇa grantha tithi-cakra*, based on *Sūrya-siddhānta,* which has been in vogue in the Andhra Pradesh for the last 571 years, was written by one Narasiṃha, who belonged to a village named Naupurī or Vadapalli in the Godāvary delta called Konasīma. He prescribes computations of the mean positions from the noon of the first day of the 1333 Śālivāhana Śaka (A.D. 1411), as per the *Cāndramāna* or luni-solar reckoning. It is interesting to note his beginning verses which report that one Mallikārjuna wrote a work called *Tithi-cakra* long before him, probably prior to A.D. 1000 (even before Bhāskara's time) which had been in vogue, but got obsolete. Hence, he said that he was writing a fresh *karaṇagrantha,* bringing it into accord with the *Sūrya-siddhānta.* Since our present *Sūrya-siddhānta,* which is now very popular, was not this popular, about A.D. 1000 (for otherwise Śrīpati and Bhāskara would not have written their monumental treatises) it may be surmised that, the *karaṇagrantha* of Mallikārjuna Sūri was not based on the present *Sūrya-siddhānta* but perhaps on some other Siddhānta possibly the *Sūrya-siddhānta* contained in Varāhamihira's *Pañca-siddhāntikā.* One word here about the so called "obsoleteness" of a *karaṇa-grantha* is not out of place here. Since *karaṇa granthas* are but manuals intended for easy computation, they can not but use approximations. These approximations go in course of time beyond the limits of negligibility, so that fresh *Karaṇa granthas* had got to be written again. An example here will clarify the case in point. We have what is called a leap year, in which we add a day to February, which means that we construe that the year consists of 365.25 days. This convention of the leap year therefore grows obsolete in course of time, so that we are obliged to make another convention that A.D. 2000 will be a leap year, but not 2100 A.D. or 2200 A.D. or 2300 A.D. though they are all divisible by four as per the leap-year convention. So is the case with respect to the obsoleteness of *Karaṇagranthas*. This is all by the bye.

To compute the mean planetary positions say at the noon of the first day of this Śālivāhana Śaka year 1904 as per the *cāndramāna* we have to note here that the major Hindu astronomical works used Śālivāhana Śaka, not Vikrama Śaka, which is in vogue in north India, and also used *cāndramāna,* not the *sauramāna,* which is in vogue in Tamil Nādu, Kerala etc. By the major siddhāntas, we mean (1) *Āryabhaṭīyam*

(2) *Pañcasiddhāntikā* of Varāhamihira, (3) Lalla's *Śiṣyadhivṛddhidam,* (4) *Brāhma-sphuṭa-siddhānta,* (5) Śrīpati's *Siddhānta-śekhara,* and (6) Bhāskara's *Siddhānta-śiromaṇi.* In between Brahmagupta and Śrīpati, there was however another great astronomer named Muñjāla (A.D. 932), whom Bhāskara quotes as having given the correct rate of secular precession not the libration theory postulated in the *Sūrya-Siddhānta.*

All the above-cited siddhānta treatises give the following procedure to obtain the mean positions of the planets at any time. Let us illustrate the procedure basing on Narasiṃha's *Tithi-cakra* cited above, which gave the mean planetary positions on the 1st day of the *cāndramāna* Śaka year of 1333 (i.e. A.D. 1411). On this behalf, we have got to calculate the number of days elapsed after the above date up to the 1st day of this Śālivāhana year 1904 (A.D. 1982) as per *cāndramāna.*

I step

$$\begin{array}{rl} 1904 & \\ -1333 & \\ \hline 571 & \\ \times\ 12 & \\ \hline 6852 & \\ 0 & \text{months elapsed during this Śaka year of 1904} \\ \hline 6852 & \text{months elapsed after 1333 Śaka year.} \end{array}$$

II step—To calculate the *adhikamāsas,* which occurred in between 1333 and 1904 Śaka years.

$$\begin{array}{r} 6852 \\ \times\ 3 \\ \hline 20556 \\ +\ 82 \\ +\ 15 \\ \hline \end{array} \qquad \begin{array}{l} 248)20556(82 \\ \qquad\qquad 220 \text{ remainder} \end{array}$$

$$\begin{array}{rl} 98)20653(210 & \text{Required number of } \textit{adhikamāsas} \\ 73 & \text{remainder} \end{array}$$

III step—To find the *tithis* elapsed from the Ist day of 1333 Śaka to the first day of 1904 Śaka year.

$$\begin{array}{rl} 6852 & \text{solar months} \\ +\ 210 & \textit{adhikamāsas} \\ \hline 7062 & \textit{cāndramāsas} \\ \times\ 30 & \\ \hline 211860 & \textit{tithis} \\ +\ \ 1 & \text{first } \textit{tithi} \text{ of 1904 Śaka year} \\ \hline 211861 & \end{array}$$

IV step—To compute what are called *kṣayāhas*

708)211861(299
69 remainder

211861
\+ 299

64)212160(3315 No. of *kṣayāhas*.
0 remainder

V step—To obtain the number of civil days or what are called *sāvanāhas* in between the Ist days of 1333 Śaka year and 1904 Śaka year

212161
— 3315 *kṣayāhas* to be subtracted from *tithis*.

208846

VI step—To ascertain the truth, divide by 7, and seek the remainder to fix the week-day.

7)208846(29792
2 remainder

But we are directed to count from Wednesday, which was the Ist day of 1333 Śaka year, which means that we have by the above remainder 2, Thursday. But since the Ist day of 1904 Śaka *cāndramāna* year happens to be Friday, we are permitted to add (or subtract) one only, no more to adjust to the week day. So, we add one to obtain Friday, so that the number of civil days, which have elapsed in between the two dates is 208846+1=208847.

NOTE :—In the proximity of the occurrence of another *adhikamāsa,* also, we are asked to be careful. If the number of *adhikamāsas* does not correspond to actuality, in the face of the *adhikamāsa,* we are permitted to add one and get the correct number of *adhikamāsas*.

One may wonder, what the rationale behind this procedure is to obtain the number of civil days which have elapsed between the two epochs. Today, we are aware of the Julian days, so that had we known the Julian days corresponding to the two epochs, this laborious process could have been avoided. But since the finding of the Julian day of the Ist day of 1333 Śālivāhana Śaka *cāndramāna* year is equally difficult, we cannot but follow the procedure indicated above. Had the two epochs been solar, we could have easily multiplied the number of years 571 by 365.25875 as per Āryabhaṭa's year or by 365.25844 as per Brahmagupta, Śrīpati and Bhāskara. Today we know the lengths of the sidereal year to be 365.256362 and the tropical year to be 365.2421955.

The rationale behind the computation of the number of civil days between two epochs is a long story, but we have got to note it, to understand our Hindu astronomical works. We know that the concept of the lapse of an year arises to a man of the world by recurrence of seasons which happens in accordance with the tropical year. Similarly the concept of the lapse of a month in olden days, when the modern system of dating was not in vogue, arose to those men, out of the recurrence of full-moon days, or new-moon days. It will be noted here that even today the illiterate men of our country in villages go by these full-moon days or new-moon days only, to understand the lapse of the month. The interval between the moments of two consecutive full-moons or two consecutive new moons, is called a lunation. It need not be added that the moment of full-moon is when the Moon has exactly an elongation of 180° and that the moment of new moon, when the elongtion of the Moon is 360°, i.e. when the Moon is in conjunction with the Sun. The correct length of a lunation as per Modern astronomy is 29.5305881 days. It is noteworthy that this length is given to be 29.5305879 in *Sūrya-Siddhānta* which is correct to six places of decimals. On the other hand, the length of a lunation as given by Brahmagupta, and followed (unwittingly) by Śrīpati and Bhāskara, is not this correct. This means that the author of *Sūryasiddhānta* did improve upon Brahmagupta's data, though he was not such a mathematician as Brahmagupta. Śrīpati and Bhāskara who were good mathematicians, were tempted to follow Brahmagupta, because the latter was a great mathematician. It will be noted further, that the *Sūrya-siddhānta,* apart from its more correct data, betrays lack of depth in other matters, where Bhāskara exhibited his genius. This is by the bye.

Coming to the point, the problem on hand is to find the number of civil days which had elapsed between the first day of 1333 Śaka year and that of the present 1904 Śaka year. In the first place, we note that the number of years which had elapsed is 571. But are these purely solar years? No, because, though the intercalation of *adhikamāsas,* went on effecting an accordance between the *cāndramāna* and *sauramāna,* after the last intercalation, again there has been a divergence between the two. Hence the number 571 is not exactly equal to the number of solar years, but a little different. Nonetheless we are asked to multiply the number 571 by 12 to get the number of solar months. Thus we get the number 6852. Then we are asked to add the number of lunar months to this. Since, we have chosen the epoch namely the first day of the Śaka year 1904, no lunations have elapsed. Suppose we add a few lunar months to the number 6852. Does this not mean a jumbling of matters? No; because, solarity so to say, has been secured upto the last intercalation of an *adhikamāsa*, and construing a few lunations added to a big number of solar months does not affect out procedure intended to calculate the number of *adhikamāsas*. Now the procedure given by Narasiṃha to obtain the number of *adhikamāsas* amounts to saying that the *adhikamāsas* in 6852 months (mostly solar but just a few lunar) $= \dfrac{3\times 6852(1+\frac{1}{248})+15}{98}$. Here evidently $\frac{15}{98}$ is the fraction of *adhikamāsa* accrued upto the first day of 1333 Śaka year, so that $6852\left(3+\dfrac{3}{248}\right)$ gives us the number of *adhikamāsas* in 6852 solar months. The rationale of this may be given as

follows. Our ancient Hindu astronomers were conversant with continued fractions as will be seen from Bhāskara'.. *Bījagaṇita*. Hence taking the data from *Sūrya-siddhānta* which says that there are 1593336 *adhikamāsas* in 51840000 solar months or what is the same 66389 *adhikamāsas* in 2160000 solar months converting $\frac{66389}{2160000}$ into a continued fraction, we have $\frac{1}{32}\,\frac{1}{+1}\,\frac{1}{+1}\,\frac{1}{+8}\,\frac{1}{+1}\,\frac{1}{+1}\,\frac{1}{+5}$ so that the convergents are $\frac{1}{32}, \frac{1}{38}, \frac{2}{65}, \frac{13}{425}, \frac{15}{488}, \frac{25}{911}.$ Since we know the convergents are alternately greater and smaller than the actual fraction, which is converted into continued fraction, what the ancient Hindu astronomers did was to add the numerators to form the numerator and add the denominators to form the denominator of two successive convergents, which will give a closer approximation to the actual fraction. Thus framing a convergent out of the convergents $\frac{1}{38}$ and $\frac{2}{65}$ we have $\frac{3}{98}$ nearer to the fraction. But by taking $\frac{3}{98}$ as the convergent, the error committed was sought to be rectified. Now going back to the original fraction $\frac{66389}{2160000}$ and considering the difference between it and $\frac{3}{98}$ taken, we have $\frac{66389}{2160000} - \frac{3}{98} = \frac{26122}{98 \times 2160000}$

$$\text{i.e. } \frac{68389}{2160000} = \frac{3}{98} + \frac{26122}{98 \times 2160000} = \frac{3}{98} + \frac{3}{\dfrac{98 \times 6480000}{26122}}$$

$$= \frac{3}{98} + \frac{3}{98 \times 248} = \frac{3}{98}\left(1 + \frac{1}{248}\right)$$ as given. Thus getting the number of *adhikamāsas,* we are directed to add them, i.e. 210 to the number of elapsed months 6852, so that the lunations elapsed are 7062. In this context, there is one more idea. As per the convention that a lunation which does not contain a *saṃkrānti* (transit of the Sun from one *Rāśi* to another *Rāśi,* where the *Rāśis* are Meṣa, Vṛṣabha etc) it so happens that occasionally two *saṃkrāntis* may occur in the three longer lunar months like Kārtika, Mārgaśīrṣa and Pauṣa. Another convention is therefore necessitated and the convention now made is, that the lunar month is called a *kṣayamāsa,* when two *saṃkrāntis* occur in a lunation. When such a *kṣaya* month occurs, two lunar months are deemed to lapse away in one lunar month. For example let Pauṣa be the lunar month in which two *saṃkrāntis* occur (this is indeed the case during this 1904 Śaka year). Then by convention we are directed to call this *kṣaya* month as *yugalibhūta-pauṣa-māgha māsa,* which means that the lunar month Māgha is also deemed to lapse away simultaneously. In the forenoon Pauṣa *māsa* is supposed to be current and in the afternoon Māgha for ritualistic purposes. In other words, Pauṣa will be running from the previous mid-night up to the noon and Māgha *māsa* current from the noon to the next mid-night. This *kṣaya māsa* is otherwise called *aṃhaspatimāsa.* Then the question arises whether we should not subtract this *kṣaya māsa,* when we are directed to add the *adhikamāsas* to the solar months. The answer is not necessary.' The

reason is, that when such a *kṣaya* month occurs it is preceded and followed by an *adhikamāsa* during the course of one solar year. This happens so because, when the *cāndramāna* overtakes the *sauramāna,* by one lunation, an *adhikamāsa* must occur. In this context Bhāskara says, that when the accrued difference between the luni-solar reckoning which is called *adhimāsa-śeṣa,* at the beginning of the Śaka year amounts to 21 days, during the first five lunations following, the luni-solar reckoning is bound to overtake the solar by the remaining nine days. So that the *cāndramāna* will have overtaken the *sauramāna* by a lunation. Thus during the sixth month, i.e. Bhādrapada there will not be a *saṃkrānti.* Hence by convention it is called an *adhikamāsa.* Under such circumstance, a *saṃkrānti* will have occurred on the last day of Śrāvaṇa, and the next *saṃkrānti* will have occurred on the first day of Āśvayuja. The month in between namely Bhādrapada does not therefore carry a *saṃkrānti* and as such is called an *adhikamāsa.* But the subsequent months, if not Āśvayuja, the next three lunar months being longer than the corresponding solar months, because then, the Sun, being near this perigee, will be moving fast, and will be covering the 30° of the solar month in lesser time, which means that the solar month will be shorter than the lunar month. Then since a *saṃkrānti* has taken place just on the first day of Āśvayuja, then either in Kārtika, or in Mārgaśirṣa, or at the latest in Pauṣa, which three lunar months are longer than the corresponding solar months, two *saṃkrāntis* are bound to occur (Ref. Fig. below) :

Srāvaṇa α Bhādrapada β Āsvayuja γ Kārtika δ Mārgaśira ϵ Pauṣa ϕ Māgha

A B C D E F G

Note that BC is Bhādrapada, does not carry a *saṃkrānti*; hence Bhādrapada is made and *adhikamāsa.* AB = Srāvaṇa, BC = Bhādrapada, CD = Āsvayuja, DE = Kārtika, EF = Mārgaśira, FG = Pauṣa

α, β, γ, δ, ϵ, ϕ are *saṃkrāntis.* Note that two *saṃkrāntis* occur in Pauṣa. There is the possibility that these two *saṃkrāntis* may occur even in Mārgaśira or even in Kārtika. Again within one year, since two *saṃkrāntis* have occured in Pauṣa, and the latter lunations Māgha, Phālguna, Caitra, Vaiśākha, Jyeṣtha and Āsāḍha are at the latest. Śrāvaṇa are gradually smaller than the corresponding solar months, one of these latter lunations stand to loose a *saṃkrānti,* and as such becomes another *adhikamāsa.*

Since a convention was made that if a lunar month did not contain a *saṃkrānti,* it should be called an *adhikamāsa,* another convention was called for, when two *saṃkrāntis* occurred in one lunar month. The convention made was, that such a month be called a *kṣayamāsa.* Now, the *adhikamāsa* which occurred in Bhādrapada, occurred so because the *cāndramāna* has overtaken the *sauramāna* by one lunation. But on account of the second convention, a lunar month is now suppressed in the name of a *kṣayamāsa.* So the lunar month gained is lost now. But as per calculations, the *cāndramāna* reckoning did gain one lunar month over the solar. So another subsequent lunar month is bound to be devoid of a *saṃkrānti,* so that, we must have an *adhikamāsa* again occurring after the *kṣayamāsa.* The former *adhikamāsa* which occurs in Bhādrapada is called *saṃsarpa māsa* in contradistinction to the

appellation *adhikamāsa,* and the second *adhikamāsa* occurring after the *kṣayamāsa* is termed as the regular *adhikamāsa.* In this context, it is worth noting that the *Kṛṣṇa Yajurveda* speaks of this phenomenon of the *kṣayamāsa,* and the preceding *adhikamāsa** signifying that the process of intercalation is as old as the Veda. This should disabuse the minds of those that Hindu astronomy was crude by the time of the *Vedāṅga Jyotiṣa* (in this context the reader is referred to the introduction of the author in his English commentary on Bhāskara's *Siddhānta-śiromaṇi* published by the Kendriya Samskrit Vidyapitha, Tirupati).

The mathematics in the context of these *adhika*-and *kṣayamāsas* runs as follows. We take the data from Bhāskara. He says that 1,593,300,000 *adhikamāsas* occur in a *kalpa* of 4,320,000,000 years or what is the same 5311 *adhikamāsas* in 14400 solar months. Converting $\frac{14400}{5311}$ into a continued fraction we have

$$2\frac{1}{+1}\;\frac{1}{+2}\;\frac{1}{+2}\;\frac{1}{+6}\;\frac{1}{+1}\;\frac{1}{+1}\;\frac{1}{+7}\;\frac{1}{+8}\;\frac{1}{+2}$$

The successive convergents are

$$\frac{2}{1},\ \frac{1}{3},\ \frac{3}{8},\ \frac{19}{7},\ \frac{122}{55},\ \frac{141}{62}.$$

Let us see what these convergents signify. The convergent $\frac{19}{7}$ means that roughly speaking there are 7 *adhikamāsas* during 19 years. This ratio was adopted in the *Romaka siddhānta* of *Pañca-siddhāntikā.* It means that $19\times12=228$ solar months are equal to 235 lunations. The Metonic cycle described in modern astronomy is based on this equivalence. Given the English date we can calculate the *tithi* as per this equivalence very approximately. In the verse 7 under *adhimāsa nirṇaya, Gaṇitādhyāya,* Bhāskara mentions that the *kṣaya* months may occur in 19 years or 122 years or 141 years. These are seen by the next convergents cited above. The interval between a new-moon and the next *saṃkrānti* goes by the name *śuddhi.* It is the interval gained by the *cāndramāna* over the *sauramāna.* Hence if this year, this *śuddhi* happens to be 21 days, as mentioned by Bhāskara, there is the possibility of the same amount of *śuddhi* occurring after 19 years or 122 years or 141 years respectively more closely. In this context, it will be noted that since Śrīpati was the first astronomer so far as we know, who made a mention of *kṣayamāsa,* some modern interpreters construed that the observance of *kṣayamāsa* came into vogue only after Śrīpati. This is not correct, in the light of the *Kṛṣṇa-yajurveda* text cited. Observance of the *kṣayamāsa* and *adhikamāsa* is therefore as old as the Veda. Simply because *Vedāṅga-Jyotiṣa* gives us a crude presentation of this phenomenon, most modern interpreters are prone to construe, that astronomy was that crude in India in about 1000 B.C. It must be remembered that substandard texts are being written even today, when high

*The fourteen lunations occurring in an year which carries a *kṣayamāsa* are enumerated in 1-4-15 in *Kṛṣṇa Yajurveda Saṃhita* as follows :
Madhu = Caitra, *Mādhaba* = Vaiśākha, *Śukra*=Jyeṣtha, *Śuci*=Āṣāḍha, *Nabhas* = Śrāvaṇa, *Nabhasya* = Bhādrapada, *Iṣa* = Aśvayuja, *Ūrja* = Kārtika, *Sahaḥ* = Mārgaśira, *Sahasya* = Pauṣa, *Tapa* = Māgha, *Tapasya* = Phālguna, *Saṃsarpa* = the *adhikamāsa* preceding the *kṣayamāsa*, *Aṃhasputi* = *Kṣayamāsa*

standard books are also being written. In this context the reader is referred to the Report of the Calendar Reform Committee (published by the Government of India in 1955) page 250, where the following para occurs: "It will be seen from the above table that according to *Sūryasiddhānta* calculations, one *kṣaya* month occurs on average in 63 years. In rare cases, they occur after 46, 65, 76, 122 years." The figures 63, 46, 76 are wrong, for the following reason.* *Sūrya-Siddhānta* gives that 1,593,336 *adhikamāsas* occur in 4,320,000 solar years or what is the same 66389 *adhikamāsas* occur in 180000 solar years. Converting

$\frac{180000}{66389}$ into a continued fraction we have

$$2\ \frac{1}{+1}\ \frac{1}{+2}\ \frac{1}{+2}\ \frac{1}{+2}\ \frac{1}{+6}\ \frac{1}{+2}\ \frac{1}{+1}$$ so that the convergents are

$$\frac{2}{1},\ \frac{3}{1},\ \frac{8}{3},\ \frac{19}{7},\ \frac{122}{45},\ \frac{263}{97},\ \frac{385}{142}.$$

Hence a *kṣayamāsa* may occur in 19 years or 122 years or combining the convergents $\frac{19}{7}$ and $\frac{122}{45}$, adding the numerators to form the numerator and the denominators to form the denominator since such a convergent lies nearer the original fraction.

We have $\frac{141}{52}$, so that as Bhāskara said, a *kṣaya* month may occur even in 141 years. On no account, could a *kṣayamāsa* occur in 46,63,65, and 76 years as reported by the Report of the Calendar Reform Committee. In this context, it is interesting to note that Gaṇeśa Daivajña spurred by Bhāskara's prediction of the occurrence of *kṣayamāsa* in the Śaka years 1115, 1256, 1378 (Bhāskara also said that a *kṣayamāsa* had occurred in 974 Śaka) also computed the years in which the *kṣayamāsa* would occur subsequent to his time. The years given by him as per *Sūrya-siddhānta* are 1462, 1603, 1744, 1885, 2167, 2232, 2372, 2392, 2524, 2533, 2655, 2674, 2796, 2815, and that as per *Āryabhaṭiyam* 1482, 1793, 1904, 2129, 2186, 2251 all Śaka years. It will be noted that in 1885 was observed a *kṣayamāsa.*

After the lapse of 19 years as mentioned by Bhāskara during this 1904 Śaka year also, a *kṣayamāsa* is going to occur in the ensuing Pauṣa month. Gaṇeśa predicted this as per *Āryabhaṭiyam.*

In the above calculation, since one *adhikamāsa* occurs in 32½ solar months, and a lunation and a solar month do not differ much from each other, construing that the months obtained namely 6852 as purely solar though they are not so, for *the purposes of calculating the adhikamāsa* is justifiable. After all, it must be noted that out of the 6852 months, there will be just a few lunar months mixed up, which therefore does not matter.

*The author of this paper makes bold to point out that the Report betrays in many places lack of touch with the *Siddhānta* texts.

After thus getting the number of *adhikamāsas,* which have elapsed we are asked to add them to the months 6852 to get the lunar months, which have elapsed. Now we are asked to multiply these lunar months by 30 to get the *tithis* elapsed. Since the epoch we have chosen, is the *first* day of this Śaka Year 1904, we are asked to add one to this, so that we have 211861 as the *tithis,* which have elapsed. The next step is to obtain what are called *kṣayāhas,* which have got to be subtracted from the *tithis* to give us the elapsed number of civil days from the 1st day of 1333 Śaka.

Let us see now what these *kṣayāhas* are, and why we are asked to subtract them from the *tithis* to get the number of civil days. It was already mentioned that a lunation contains 29.5305879 days as per *Sūrya-siddhānta,* i.e. one *tithi* corresponds nearly to one day, but falls short of a day by a fraction .47 roughly or .4694121 correctly. Hence during a period of 30 *tithis* there is a shortage of .4694121 days which means roughly that one *tithi* will be lost approximately in 64 days. There is a convention that a day should be dated by the *tithi* which is current on that day at sunrise. Suppose today a particular *tithi* daśamī is current at sunrise, but lasts just for a few moments. Then the next *tithi* being shorter than a day may lapse away. Thus tomorrow will be dated not by ekādāsī but by dvadasī. Thus we have lost the *tithi* ekādaśī, which is therefore called a *kṣayāha.* One such *kṣayāha* occurs in a period of 64 *tithis.* To compute these *kṣayāhas* accurately the procedure given by Narasimha in the fourth step as cited before, is to divide the *tithis* obtained namely 211861 by 708, and add the quotient to 211861 and then divide it by 64 and take the quotient. The rationale here is as follows. As per *Sūrya-siddhānta* there are 1603000080 *tithis* and 25082252 *kṣāyahas* in a *Mahāyuga.* Hence converting $\frac{1603000080}{25082252}$ into a continued fraction, we have the convergents $\frac{1}{63}$, $\frac{1}{64}$, $\frac{11}{703}$, $\frac{122}{7797}$ etc., We see herefrom that $\frac{1}{64}$ is one convergent and $\frac{122}{7797}$ is a convergent close to the fraction than $\frac{1}{64}$. If x be the number of *tithis,* $\frac{x \times 122}{7797}$ gives the number of *kṣayāhas;* but to avoid multiplication and division by large numbers, the short-cut adopted by Hindu astronomers is to find the difference of the convergents

$$\frac{122}{7797} - \frac{1}{64} = \frac{11}{64 \times 7797}$$

$$\therefore \; \frac{122}{7797} = \frac{1}{64} + \frac{11}{64 \times 7797} = \frac{1}{64}\left(1 + \frac{1}{\frac{7797}{11}}\right)\frac{1}{64} = \left(1 + \frac{1}{708}\right)$$

as given by Narasimha. This process virtually amounts to taking the convergent $\frac{122}{7797}$ but the procedure is rendered easier. Thus getting the number of *kṣayāhas* from the *tithis* we have the required number of civil days. We must not be satisfied by the number so got. So, we are asked to divide by 7 and get the remainder. The remainder got is two. But the 1st day of 1333 Śaka year was Wednesday. So by this remainder, we get Thursday. Since the first day of 1904 Śaka year is Friday, we have to add one

to adjust the *ahargaṇa* to the week day. Adding or subtracting one is permissible because we are introducing approximations.

Thus far we have got the number of civil days which have elapsed from the 1st day of 1333 Śaka year to the 1st day of this Śaka year 1904. Since we are given the positions of the planets on the 1st day of 1333 Śaka year by Narasimha, the next step is to get the motion of the planets during these 208847 days and add these motions to their positions as given on the 1st day of 1333 Śaka year.

However, we must note that the positions of the planets as given by Narasimha on the 1st day of 1333 Śaka year, are those pertaining to the Laṅkā meridian. For a meridian different from this a correction called *deśāntara* is to be effected in those positions either before computing the mean motion due to 208847 days and adding it to the mean positions given on the 1st day of 1333 Śaka year or after getting the mean positions as on the 1st day of 1904 Śaka year. It does not matter.

The mean motion of a particular planet during an *ahargaṇa* say x (here $x=208847$) we have to proceed as follows. The *Sūrya-siddhānta* says in verse 55 Chapter 1, $x \times R$ gives the motion of the planet in x days, where R is the number of its sidereal revolutions in a *Mahāyuga* and D is the number of days in a *Mahāyuga*. Let us take the case of Saturn for example. *Sūrya-siddhānta* says that Saturn makes 146568 sidereal revolutions during the days of the *Mahāyuga* namely 157791828. The arc moved by Saturn in our *ahargaṇa* of 211861 days is hence $\frac{211861 \times 146568}{157791828}$
This multiplication and division is laborious, so that easy procedures are generally given in the *karaṇagranthas*. In the case of the Moon, $R=57753336$ so that it is indeed more laborious to effect the multiplication. Anyway the procedure is clear to obtain the mean motion of any planet from this formula taking the respective values of R in the case of each planet. Adding the mean motion of each planet during the course of the *ahargaṇa* calculated, to its position as given in the *Karaṇagrantha*, we get the mean planet for the midnight of Laṅkā as per *Sūrya-siddhānta*. The number of revolutions can be clearly omitted, to note the planetary position on the zodiac, even as time is noted from a clock, ignoring the number of revolutions of the hour hand.

Hindu astronomers gave the inclinations of the planetary orbits to the ecliptic. Yet, since these inclinations are generally small, no account is taken with respect to the planets except in the case of the Moon, when a lunar eclipse or solar eclipse is to be computed. In this case the latitude of the Moon will come into the picture.

Since the mean planetary positions are obtained for the Laṅkā meridian, we effect the *deśāntara* correction to obtain their positions for the midnight of the particular place at which its position is required. The next step will be therefore to compute the planetary position for the moment of the sun-rise at the place. This entails finding the lengths of the day and night for the required moment.

NOTE ON THE CALCULATION OF AHARGANA

The method of calculation of *ahargaṇa* from the beginning of *Kaliyuga* upto 28-7-1984, i.e. *Āṣāḍha Bahula Amāvāsyā* of this *Raktākṣi Samvatsara* as per *Siddhānta Śiromaṇi* of Bhāskara II is explained as follows :

The number of years elapsed of *Kaliyuga* 5085

$$\begin{array}{r} 5085 \\ 12 \\ \hline 61020 \\ 4 \\ \hline 61024 \end{array}$$

4 — Add lunar months elapsed from Caitra

Then as per *Siddhānta Śiromaṇi*, the number of *adhikamāsas* in the *Kaliyuga* whose duration is 4,32000 years, i.e. 5184000 solar months is 159330.
That being so, the *adhikamāsas* which have elapsed from the beginning of Kali are as per rule of three

Solar months		*Adhikamāsas*
5184000	—	159330
61024	—	?

$$= \frac{159330 \times 61024}{5184000} = 1876 \text{ rounding up the fraction } \frac{92}{162} \text{ to unity.}$$

Add these *adhikamāsas* to the elapsed solar months 61024 (construing the four *cāndramāsas* as solar does not affect our calculation)

$$\begin{array}{r} 61024 \\ 1876 \\ \hline 62900 \\ 30 \\ \hline 1887 6000 \end{array}$$

62900 —*cāndramāsas*

Multiply by 30 to get *tithis*. Elapsed *tithis* from the beginning of Kali.

Now as per the same *Siddhānta Śiromaṇi*, the number of *kṣayāhas* during the duration of the *Kaliyuga* is 2508255, which *Kaliyuga* has 160299000 *tithis*. Hence again by rule of three, if during 1602999000 *tithis*, we have 2508255 *kṣayāhas*, what number of *kṣayāhas* will be there during the course of 1887000 *tithis*?

The answer is

$$\frac{2508255 \times 1887000}{1602999000} = 29526$$

ignoring the small remainder.

Hence subtracting these *tithikṣayas* from the *tithis* 1887000 we have 1857474. Dividing by 7, the remainder is 3.

We are told that this *Kaliyuga* started on Friday, so that the day should be Sunday. But actually the day on 28-7-1984 was Saturday. Since we are given the option to add or subtract unity if the *ahargaṇa* does not accord with the name of the day, subtracting unity from the above, we have the required *ahargaṇa* as 1857473.

THE METHOD OF FINDING THE LENGTH OF THE DAY

In modern astronomy we have the formula $\cos h = -\tan\phi \tan\delta$ to obtain the hour-angle h of the rising Sun for a place of latitude ϕ when the Sun has declination δ. When the Sun is in the northern hemisphere, δ is positive. So far as India is concerned ϕ is positive, so that when δ is positive, since $\cos h$ is negative h will be greater than 90°.

Let $h=90°+\theta$ so that $\cos(90°+\theta) = -\text{Sin}\ \theta = -\tan\phi \tan\delta$.

Hence $\sin\theta = \tan\phi \tan\delta$ .. .. .. (1)

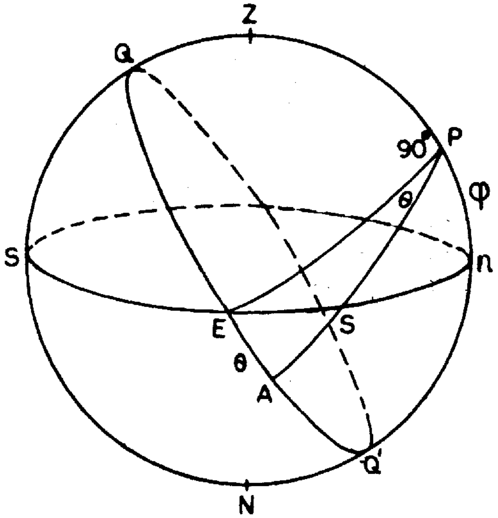


Fig. 6.1 determination of the length of the day

This θ is the arc EA in Fig. 6.1 where S is the rising Sun (when δ is north) and is called *cara* in Hindu astronomy. For a given place ϕ the latitude does not change, whereas δ the declination of the Sun changes from day to day. In Hindu astronomy instead of specifying ϕ in degrees, what is called *palabhā* is used. This *palabhā* is the shadow of a vertical gnomon divided into 12 units called *aṅgulas*, at noon on the equinoctial day. On the equinoctial day at noon the Sun is that Q which is the point of intersection of the celestial equator with the meridian. From Fig. 6.2 $\tan\phi = \frac{s}{12}$. This *palabha* is also given in the same units of *aṅgulas*, so that if

$s=4 \tan\phi = \frac{4}{12} = \frac{1}{3} = \cdot 3333$ so that $\phi = 18°\ 25'$.

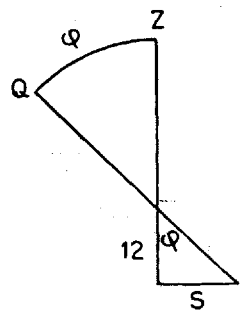


Fig. 6.2 determination of the *palabhā*

Since the *cara* is added to 90°, when δ is positive and subtracted from 90° when δ is negative to obtain the rising hour angle of the Sun, which gives the length of the day, the question resolves itself into our finding this *cara,* for varying declinations only since ϕ is constant for a place. We have the formula sin $\delta=$ sin λ sin ω where sin ω, the obliquity of the ecliptic, is again constant. Since ω was taken to be 24° by the Hindu astronomers, the formula is therefore

$$\text{Sin } \delta = \sin 24° \sin \lambda \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

But λ is measured along the ecliptic from the equinoctial point γ. The Hindu longitude of the Sun is measured from the first point of Aświnī, and the positive arc in between γ and the Hindu Zero point gives what are called *ayanāṃśas.* The Hindu longitude is called the *nirayana* longitude and that measured from γ is called the *sāyana* longitude. Hence before we find δ from formula (2), we have to add the *ayanāṃsas* to the Hindu longitude of the Sun, to get λ.

Hindu astronomy uses what are called *carakhaṇḍas,* taking the equinoctial shadow to be one *aṅgula,* i.e. taking tan $\phi=\frac{1}{12}$. Since sin $\theta=$tan δ, tan ϕ, sin $\theta=$tan $\delta\times\frac{1}{12}$ for the *palabhā* of one *aṅgula* and sin $\theta=$tan $\delta\times\frac{s}{12}$ for a *palabhā* of *s aṅgulas.* Taking $\omega=24°$, (we may rectify the results taking the present value of ω) following the same procedure for the values 30°, 60° and 90° for λ, have

$$\sin \delta_1 = \sin 24° \sin 30° \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3)$$
$$\sin \delta_2 = \sin 24° \sin 60° \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (4)$$

δ_3 is of course equal to 24°

Taking logarithms

Log sin δ_1 = 9.6990+9.6093 = 9.3083

so that δ_1 = 11°44′.

Log sin δ_2 = 9.9375+9.6093 = 9.5468

so that δ_2 = 20°38′

From (1) sin θ = tan δ tan ϕ

$$\therefore \sin \theta_1 = \frac{\tan 11° 44'}{12}, \text{ for } \tan \phi = \frac{1}{12}$$ for a *palabhā* of 1 *aṅgula,* and δ_1 corresponding to $\lambda = 30°$, being 11°44′.

Similarly, $\sin \theta_2 = \dfrac{\tan 20° 38'}{12}$, θ_2 corresponding to $\lambda = 60°$ and

$\sin \theta_3 = \dfrac{\tan 24}{12}$ corresponding to $\lambda = 90°$.

Taking logarithms and proceeding as before, $\theta_1 = 59'$, $\theta_2 = 1°48'$ and $\theta_3 = 2°8'$.

Converting degrees and minutes at the rate of 6′ per *vināḍī* (1 *vināḍī* = 24″ of time). We get :

θ_1 = 10 *vināḍis,* θ_2 = 18 *vināḍis* and θ_3 = 21 $\frac{1}{3}$ *vināḍis.* In other words θ_1= 10; $\theta_2-\theta_1=8$ and $\theta_3-\theta_2=3\frac{1}{3}$. These 10, 8, and $3\frac{1}{3}$ are called *carakhaṇḍas* corresponding

to λ varying between 0° and 30° and varying between 30° and 60° and again between 60° and 90°. For a given place of equinoctial shadow *s aṅgulas,* we have *cara* segments 10, 8 and $2\frac{1}{3}$ multiplied by s''. This proportionality is approximate because the formulae $\sin \theta_1 = \dfrac{\tan 11°44'}{12}$ etc, have not θ_1, θ_2, θ_3 on the left-hand side but $\sin \theta_1$, $\sin \theta_2$, $\sin \theta_3$.

Bhāskara gives in verse 49 of *spaṣṭādhikāra,* that if *s* be three *aṅgulas,* then the *carakhaṇḍas* are 30, 24, 10, in *vināḍis*. If it be required to find the *carakhaṇḍa* for $\lambda=44°$ (say) we are asked to proceed as we do with the interpolation formula given by him with respect to getting the values of sines in the name of *bhogyakhaṇḍa sphuṭikaraṇa.* It is worth-noting here that this *bhogyakhaṇḍa sphuṭikaraṇa* was originally given by Brahmagupta and this interpolation formula agrees with the quadratic interpolation formula given by Ball in his *Spherical Astronomy* on page 18 which has the form

$$Y = Y_0 + \frac{x}{h}\,(y_1 - y) + \frac{x\,(x-h)}{2h^2}\,(y_2 - 2y_1 + y_0)$$

where y_0, y_1, y_2 are three consecutive values of the function of y, h is the constant difference of the arguments. Then for any argument which is greater by x than the first argument, but less than the third argument, the above formula gives the required function. The formal 'rule-of three' is a linear interpolation formula, whereas the *bhogyakhaṇḍasphuṭikaraṇa* is a quadratic interpolation formula.

Adding the *cara vināḍis* to 15 *nāḍis* when δ is positive and subtracting them from 15 *nāḍis* when δ is negative, we have what is called *dinārdha* or half the daytime. Double this gives the duration of the day-time. Subtracting the duration of day-time from 60 *nāḍis,* we get the duration of the night. Having got the duration of half the night, the mean planetary positions are to be rectified to get their positions at sunrise. The *deśāntara saṃskāra* may be applied now or prior to this procedure.

Epicyclic and Eccentric Theories and Planetary Corrections

Having obtained the mean planetary positions on a particular day at sunrise for any place, the next procedure is to rectify these mean positions by applying the necessary corrections called *saṃskāras,* to obtain their True positions at the place. The *saṃskāras* to be applied are of two kinds (1) *manda saṃskāra* (2) *śighra saṃskāra.* With respect to the Sun and Moon, the first *saṃskāra* suffices to obtain their true position,[9] where as, for the five planets called *Tārāgrahas* namely Mercury, Venus, Mars, Jupiter and Saturn both the *saṃskāras* are necessary. The reason for this is simple. The Moon goes in an allipse around the Earth; the Earth being in one focus, whereas the Sun goes relatively round the Earth, the Earth being in one focus (we say relatively because it is the Earth going round the Sun, in an ellipse, the Sun being in one focus as per Kepler's first law). The mean planetary positions signify that we have presumed that the planets are going in a circle, as a first approximation. The *manda-karma* is there-

fore intended to get the corresponding position in the ellipse from the position in the circle (though not stated so).

It will be noted however, that Hindu astronomical texts do not say that the planets are going round in ellipses. They say that they go in an epicycle, whose centre moves along the mean circular orbit from west to east. This theory is called the epicyclic theory. There is another theory called the Eccentric theory, which says that the planet goes in a circle whose centre is not the Earth but a different point other than the Earth. The distance of this point from the Earth, is said to be equal to the radius of the epicycle. We shall presently see how both the theories are identical.

In the first place, we shall consider the eccentric theory. Bhāskara says here "The centre of the celestial sphere coincides with the centre of the Earth. The circle in which the planet goes does not have its centre coinciding with the centre of the Earth." Hence, astronomers prescribed what is called *bhujaphalam* (otherwise called equation of centre in the case of *mandaphala,* whereas in the case of the five *tārāgrahas,* this *bhujaphala* besides connoting equation of centre or *mandaphala*, also stands for the correction required to reduce their heliocentric positions to the geocentric, as a correction to be made to obtain the true positions from the mean."[10]

ECCENTRIC THEORY

Let A be the centre of the Earth; let P be the mean planet construed to go round in a circle whose centre is A. (Fig. 6.3) Let B be the centre of the circle, in which the planet actually moves. It must be noted that the radii of these two circles are equal.

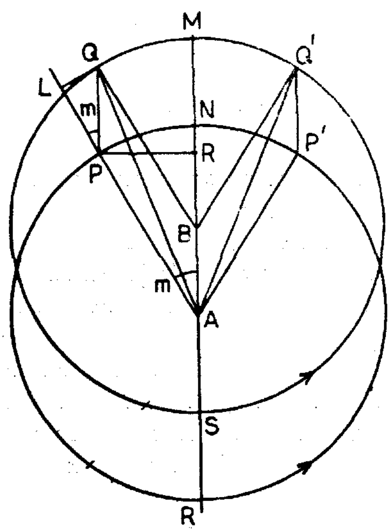


Fig. 6.3 Eccentric model for planetary manda

The circle (A) is the mean orbit, whereas the circle (B) is the true orbit. The mean planet moves on the mean orbit called by some as the deferent. The position of the true planet in the eccentric circle (B) namely Q will be such that PQ is parallel and equal to AB. In fact, PQ is drawn parallel to AB, and $AP = BQ$ by construction. By simple geometry we can prove that $PQ=AB$. Also we can see that when B is vertically above A, and when the radii of the two circles are equal, every corresponding point of the circle (A) will be vertically moved by the same distance AB. Thus $PQ=AB$ and they are also parallel. Join AQ to cut the circle (A) in T, which is said to represent the true planet.Evidently when the planet is at N in the mean orbit, the planet is at M, in the eccentric, which point is called the *mandocca*. When the planet is at R in the mean orbit the planet is at S in the eccentric. Thus M and S correspond to the apogee and perigee in the case of the *mandaphala* correction (otherwise called equation of centre). When the planet is at M in the eccentric, the position of the true planet coincides with N, the mean planet, so that the *mandaphala* correction is zero. Simlarly the true planet at R being in the same direction as AS, there also the *mandaphala* is zero. We know that the equation of centre at apogee and perigee becomes Zero similarly. When the mean planet is at P, since the true planet is at T, the correction *mandaphala* PT is negative. When the mean planet is at P' on the right, the true planet will be at T' so that the correction $P'\ T'$ is positive. The angle NAP is called the *mandakendra*, which corresponds to mean anomaly of modern astronomy. Thus when the mean anomaly lies between 0° to 180°, the equation of centre is negative, being equal to zero both when the mean anomaly is 0° and 180°. On the other hand, when the mean anomaly lies between 180° and 360°, the equation of centre is positive. In modern astronomy, it must be noted that m the mean anomaly is measured from the perigee, so that we have the reverse sign. Bhāskara and Śrīpati construe the mean anomaly in the case of the equation of centre as planet's longitude minus the longitude of the *mandocca* or apogee. In the case of what is called *śighraphala*, intended to get the geocentric planet from the heliocentric, they construe the longitude of what is called *śighrocca* minus the longitude of the planet as the *kendra*. (or mean anomaly). To use the word mean anomaly for the *kendra* here is rather awkward in modern Astronomy, but if we construe the *kendra* as the argument from which, we calculate the *śighraphala*, it will be alright. In the *Sūrya-siddhānta* however, for the sake of uniformity the *kendra* or argument from which either *mandaphala* or *śighraphala* is to be computed is taken as the longitude of the *ucca* (*mandocca* or *sīghrocca*) minus the longitude of the planet. In this case sin m will be evidently positive between the values 0° to 180° of the *kendra* and negative between 180° to 360°. It is only a matter of convention, about which, we need not bother. However, the definition of *kendra* given by Śrīpati and Bhāskara have a greater significance, which will be elaborated later. In modern asıronomy the equation of centre s is given by $2es$ in $m + \frac{5}{4}\ e^2 \sin 2\ m$.

The arc PT (Ref Fig. 6.3) is approximately taken to be equal to QL the perpendicular dropped from Q on AP produced. This approximation is permissible because

the difference will not be much in the case of the equation of centre. Since triangle APK and PQL are similar, we have

$$\frac{QL}{PQ} = \frac{PK}{AP} = \sin m$$

$\therefore\ QL = PQ \sin m = PT$ (approximately)

$=$ *mandaphala* or equation of centre comparing this with the modern formula, neglecting the second term in the equation of centre (for the present) $2e \sin m = PQ \sin m$

$\therefore\ PQ = 2e$

since $PQ \sin m$ will be maximum when $m = 90°$

$2e = PQ$ is called the *antyaphala*, i.e. maximum equation of centre. The word eccentric circle is used because the centre B of the circle in which the True planet is supposed to move does not coincide with the centre of A of the circle which is the mean orbit.

Epicyclic Theory

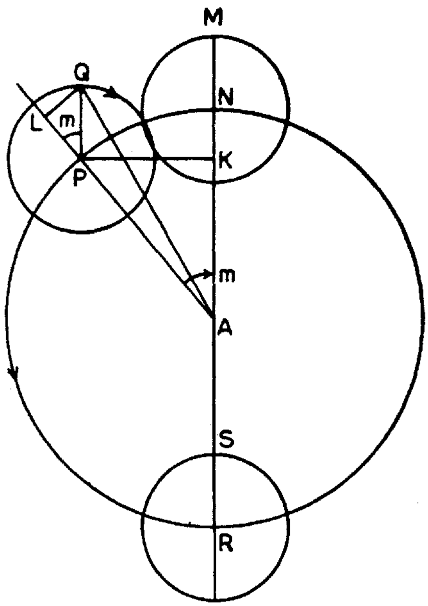


Fig. 6.4. Epicyclic model for planetary *manda* corrections.

In Fig. 6.4, the circle (A) is the mean orbit. Let P be the mean planetary position. The small circle (P) is called an epicycle. The position of the true planet Q is always taken to be such that PQ is paralled to AN. The length of PQ being equal to the length of AB in Fig. 6.3 the distance between the two centres of the mean orbit and the true orbit, it is evident that two theories the eccentric and the epicyclic give one

and the same position of the True planet. Here also the triangles, APK and PQL are similar so that taking QL equal to the arc PT approximately as before $QL=PQ$ sin m. Here also M corresponds with the perigee of the orbit.

In view of the epicyclic theory, Hindu astronomers gave instead of the value of PQ the radius of the epicycle, the circumference of the epicycles in the case of each of the planets. It appears peculiar to note that the circumferences are given in degrees or what is the same the radii also in degrees, so that the equation of centre may be got in degrees direct. The epicycle in the case of the equation of centre is termed *mandanīcoccavṛtta,* where the word *manda* pertains to the *mandaphala* or equation of centre and the word *nīca-ucca-vṛtta* signifies that the word *nīca* should be taken for perigee and the word *ucca* for *apogee,* because they are respectively nearer and farther from the Earth. The words *manda,* and *śīghra* occurring in the case of reducing the heliocentric longitudes to the geocentric have further significance, which will be explained shortly. Another point deserves notice in this context. *Sūrya-siddhānta,* and *Siddhānta-śekhara* of Śrīpati make the dimensions of the epicycles variable, whereas Bhāskara and Kamalākara, the author of *Siddhānta-tattvaviveka,* (1606 AD) do not.

Śīghra Karma Or The Correction To Reduce The Heliocentric Positions To The Geocentric

It is very interesting to note here, that, though the Hindu astronomers construe implicitly or explicitly that all the planets go round the Earth yet as per Bhāskara's statement the centre of the eccentric circle does not coincide with the centre of the Earth. The centre of the eccentric circle, so taken, it has to be noted, coincides with the centre of the Sun as the mathematics involved will reveal to us. Bhāskara gives us in verses 23-25 *Gaṇitādhyāya,* that the peripheries of the *śīghra* epicycles of Mars, Mercury, Jupiter, Venus and Saturn are respectively 243°40′, 132°, 68°, 258° and 40°. He later adds, that these dimensions are variable to some extent and specifies, where and to what extent they are variable.

As already stated, that *śīghraphala* is prescribed only for the planets Mars, Mercury, Jupiter, Venus and Saturn. This is so because, they revolve not around the Earth, but round the Sun. Hence this *śīghraphala* is intended to reduce the heliocentric positions to the geocentric.

The following table shows how there is a beautiful accordance between the Hindu Astronomy and modern astronomy in this. This itself is a proof that the point about which these five planets revolve, as postulated by Bhāskara to be some other point than the centre of the Earth is no other than the Sun. So, though it was not mentioned in so many words in Hindu astronomy, that these planets are revolving round the Sun, the mathematics which goes into computing the *śīghraphala* clearly reveals that the Hindu theory was also heliocentric. Then the question arises as to how the *śīghraphala* came to be formulated so correctly under a supposed geocentric theory. The following argument can be adduced.

TABLE 6.5. *Dimensions of śighra epicycles and their ratios with reference to the deferent circle*

Planet	Periphery of the *Śighra* epicycle	Periphery of the deferent	Ratio	Value in modern astronomy taking Earth's ortital radius to be unity
Mercury	132°	360	$\frac{132}{360} = .37$	.387
Venus	258°	360	$\frac{258}{360} = .716$	.723
Mars	$243\frac{2}{3}$	360	$\frac{360}{243\frac{2}{3}} = 1.5$	1.52
Jupiter	68°	360	$\frac{360}{68} = 5.3$	5.2
Saturn	40°	360	$\frac{360}{40} = 9$	9.6

In the case of the Sun and Moon, it was discovered that the true positions were slightly different from the computed mean positions, except at two points (namely the perigee and apogee) where they were found to be the same. These two points were noted correctly. Later, it was discovered that the Sun and Moon were being drawn towards the apogee on either side of the apse line. So the *Sūrya-siddhānta* says significantly "the planets are being attracted towards the *mandocca*, i.e. the apogee, which is an unseen entity" (verses 1 and 2 Chapter-2). Not only mention is made of the *mandocca*, but also of *śighrocca*, and the nodes playing a part in this attraction.

Noting carefully, that the divergence between the computed mean position and the observed true position was a maximum at a distance of 90° from the *mandocca* on either side, this maximum was called *antyaphala* (meaning etymologically the maximum). The amounts of divergence in between, were then discovered to vary not as *m* but *sin m*. Hence the *mandaphala* or equation of centre came to be formulated very easily in the case of the Sun and the Moon.

But when it came to the case of the five planets Mars etc., the divergence between the computed mean positions and the true positions was observed to be very great.

Then it was observed that this divergence was a minimum when these planets were in conjunction or opposition with the Sun. Soon it was discovered that the Sun was playing a part in this divergence. Since Mercury and Venus were found to be in oscillation about the mean position of the Sun, whereas the other planets Mars, Jupiter and Saturn were going round the sky, a differentiation was made between Mercury and Venus on the one side, and the other planets on the other. Also since in course of time, due to the oscillation of Mercury and Venus about the Sun, the number of sidereal revolutions of Mercury and Venus about the Earth (not about the Sun) were taken to be those of the Sun. Hence peculiarly indeed, the Sun's mean position is taken to be the mean position of the planets Mercury and Venus. Then their elongation becomes now the *śighraphala,* which is to be added or subtracted from the Sun's mean position to get their geocentric positions. In the case of Mars, Jupiter and Saturn i.e, the Superior planets as they are called in modern astronomy, it must be noted that their mean positions construed unknowinghly as geocentric by the Hindu astronomers, are indeed heliocentric. This we can realize in two ways : (1) Even if actual observations made with respect to these planets, irrespective of their retrograde motion, the mean geocentric sidereal period will be the same as the mean heliocentric sidereal period, for the simple reason that the Earth's orbit is contained within the orbits of these planets (of course a number of observations of the sidereal periods must be made to strike a mean) (2) or again if the sidereal periods were calculated from the formula

$\frac{1}{Y} - \frac{1}{P} = \frac{1}{S}$ (of course is not the formula used in this form, but it was used indirectly as follows. The difference of the sidereal revolutions of the Sun and those of the planets Mars, Jupiter and Saturn were noted to constitute the synodic revolutions of these planets) they are to be noted to be heliocentric and not geocentric.

Hence "the mean planet" in the case of the planets Mars, Jupiter and Saturn, it should be noted, is the mean heliocentric position and *not at all the mean geocentric position*. Interpreters of Hindu astronomy went wrong here, in construing the 'mean planet' in the case of the superior planets, as the geocentric mean planet. The very fact that the *śighra* correction applied to these mean planets is no other than the difference of the heliocentric and geocentric position should disabuse the minds of those interpreters. In other words by applying the *śighra saṃskāra* we are reducing the heliocentric positions to geocentric positions. This correction was observed to be zero when the planet (i.e. one of the superior planets) is in conjuction or opposition. Hence the Sun plays the same part here in the *śighra* correction as the apogee while computing the equation of centre, so that the Sun is spoken of as the *śighrocca* of these planets. In contradistinction, with respect to Mercury and Venus, since the mean Sun is taken to be their mean planet, the part played by the *mandocca* in the computation of the equation of centre, is now played by the heliocentric position of the planets Mercury or Venus. Hence, though it sounds odd, the heliocentric Mercury or the heliocentric Venus are spoken of as their own *śighroccas*. All this is connoted by the following verse "*Kujajīvaśaniṇāṃtu raviḥ śighrocca ṇā makaḥ; jna śukrayoḥ grahaḥ Sūrya bhavet tau śighraṇamakau*", i.e. in the case of the superior planets, the

Sun plays the part of the *śighrocca,* whereas in the case of Mercury and Venus, their heliocentric positions are spoken of as the positions of the *śighroccas,* whereas the mean sun is spoken of as their mean planet.

This is corroborated by the verse 8 Chapter-2 of *Sūryasiddhānta,* as well as the verse of *Gaṇitādhyāya* of Bhāskara, which says that the geocentric revolutions of the nodes of the orbits of the planets Mercury and Venus are got by increasing their (heliocentric) revolutions by the number of their synodic revolutions. In other words, the terms *śighroccas* applied to the heliocentric Mercury and Venus, indirectly implies that their motion is heliocentric and not geocentric.

Under this perspective, let us see the method of computing the *śighra-saṃskāra,* i.e. the correction to be applied to reduce the heliocentric positions to the geocentric. Let us take first the case of the superior planets, that of Jupiter for example. In modern astronomy, the equation of centre is applied to the heliocentric true planet and later the heliocentric true planet is reduced to the geocentric true planet. In Hindu astronomy, the heliocentric mean planet (though it is construed as the geocentric) when corrected for the equation of centre is called the *mandasphuṭagraha* and when then the *śighra* correction is applied we get the geocentric true or *sphuṭagraha* as it is called. However, in this a particular procedure is prescribed by Bhāskara, and another particular procedure by the *Sūrya-siddhānta* to obtain the true geocentric positions.

Bhāskara says that the mean star-planets except Mars are to be rectified for the equation of centre first. It is called the *mandasphuṭagraha.* Now subtract the longitude of this *mandasphuṭa* from the longitude of the *śighrocca.* The resultant is called the *śighra* anomaly. From this argument, obtain the *śighraphala* and apply it to the *mandasphuṭa.* The result is again taken to be the *mandasphuṭa* so that the equation of centre is again derived for this and applied to the *original mean planet* Then again, correct it for *śighraphala* and repeat the process till a constant value is obtained as the true planet. But with respect to Mars, let the mean planet be corrected for half of the equation of centre. Then derive the *śighraphala* and effect half the correction to the previous result. Now derive the equation of centre and effect the entire correction from the resulting *mandasphuṭa* and then derive the *śighraphala* and effect the whole correction. The result then gives the true planet.

Sūrya-siddhānta on the other hand, prescribes a uniform procedure to all the star-planets. In the first place, half of the *śighraphala* is the correction to the mean planet. Taking the result to be the mean planet, derive the equation of centre and effect half of this equation of centre to the previous result. Now consider the result to be the mean planet, compute the equation of centre and effect the whole correction. Taking the result to be the *mandasphuṭagraha,* compute the *śighraphala* and effect the whole correction to obtain the true planet.

As per modern astronomy, there is no connection between the equation of centre and the subsequent *śighraphala.* The former is to get the true heliocentric position.

Then the *śighraphala* is to reduce the heliocentric true planet to the geocentric. According to this, the processes prescribed by Bhāskara under the name of *āgama* and *upalabdhi*, i.e. tradition and accordance, between the computed position and the observed, or that prescribed by the *Sūrya-siddhānta,* seem to be beating about the bush. However, we shall revert to this later to see some rationale behind these procedures.

Now we shall try to interpret the *śighraphala* as no other than the correction to be effected to reduce the heliocentric position of the planet to the geocentric. In the first place, we shall consider this with respect to the Hindu epicyclic theory. In the case of the equation of centre, construing the arc PT as roughly equal to QL did not matter because of the smallness of the equation of centre (Fig. 6.5).

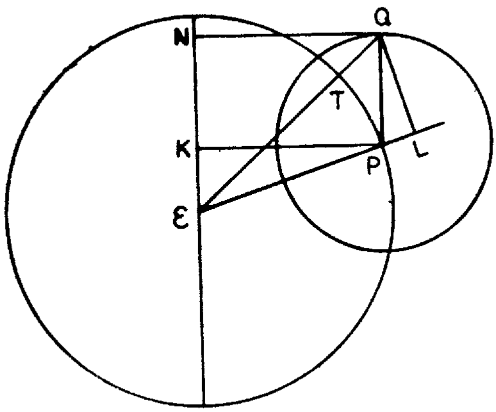


Fig. 6.5. Computation of *śighrakarṇa.*

But in the case of the *śighraphala* which is generally of a larger value, we cannot do so. Hence EQ called the *śighrakarṇa* is computed first. Bhāskara says that, this EQ (called K here) is got as follows

$K^2=EQ^2(EP+PL)^2+QL^2$ .. .. (5)

or $= EN^2+QN^2$ .. .. (6)

Here $EP=R$ (called *trijyā*) PQ is called *antyaphala* or maximum *śighraphala.* QL is termed *bhujaphala* and PL as *koṭiphala.* Also $QN=PK$ is called *bhuja,* and EK is termed *koṭi.*

Hence what Bhāskara says amounts to

$K^2 = (\textit{trijyā}+\textit{koṭiphala})^2+\textit{bhujaphala}^2$ .. .. .. (5)

or $= (\textit{koṭi}+\textit{bhujaphala})^2+\textit{bhuja}^2$ .. .. .. (6)

(5) reduces to $K^2 = R^2+a^2\pm 2\,R\,\textit{koṭiphala}$. (6) reduces to

$K^2 = R^2+a^2\pm 2a\times \textit{koṭi}$

where $EP=R$, and $PQ=a$.

The proof is simple.

We shall derive these formulae from the modern heliocentric figure also. We shall consider the case of a superior planet, say Jupiter, for example.

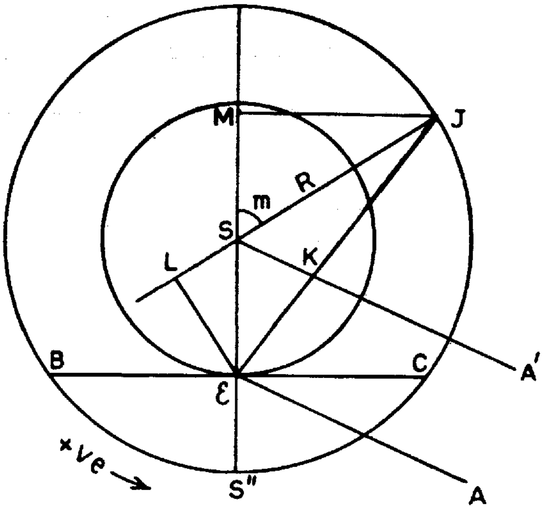


Fig. 6.6

The same formula are derivable from the heliocentric Fig. 6·6 also as follows.

In fig. 6.6 $K^2 = EJ^2 = (ES+SM)^2 + JM^2$ or $EL^2 + (LS+SJ)^2$

$\therefore$ $K^2 = a^2 + koti^2 + 2a$ *koti* + *bhuja*^{2} or *bhujaphala*^{2} + *koṭiphala*^{2} + *trijyā*^{2} + 2 *trijyā* × *koṭiphala*.

Note that *koṭi*^{2} + *bhuja*$^2 = R^2$ and *bhujaphala*^{2} + *koṭiphala*$^2 = a^2$.

Now we shall find the value of *śighraphala* both in the epicyclic fig. 6.5 and the heliocentric fig. (6.6). In fig. (6.5) construing PT, which is the *sighraphala* as a chord parallel to LQ.

$$\frac{PT}{LQ} = \frac{ET}{EQ} \text{ approximately.}$$

$$\therefore PT = \frac{ET \times LQ}{EQ} = \frac{R \times LQ}{K} \quad \text{But } \frac{LQ}{PK} = \frac{PQ}{EP}.$$

$\therefore$ Substituting for LQ

$$\therefore PT = \frac{R}{K} \times \frac{PQ}{R} \times PK = \frac{a \times pK}{K} \quad \text{But} = H \text{ Sin } m \text{ (Hindu Sine)}$$

where m is called the *śighra* anomaly.

$\therefore$ PT = *śighraphala* $= a \sin m$ where k is called the *śighrakarṇa*. In the heliocentric figure (6.6)

$$\frac{\sin EJS}{A} = \frac{\sin m}{K} \quad \therefore \sin EJS = \frac{a}{K} \sin m. \text{ Multiplying both sides by } R$$

$$H \sin EJS = \frac{a}{K} H \sin m$$

as before, where H sine signifies the Hindu sine. Thus we see that a plays the part of *antyaphala,* i.e. PQ of the Epicyclic figure. As a matter of fact, keeping the epicycle fixed, and rotating the centre E in Fig (6.5) around P, we have the heliocentric figure. In other words, both the figures lead to the same value of *śighraphala*. Or we can again see that the triangle EPQ of Fig. (6.5) is congruent to the triangle SJE of fig. (6.6), which means that we get the same result from the epicyclic figure as we get from the heliocentric figure.

We have still to establish further correspondence between figures (6.5) and (6.6). Let us consider the case of the superior planet J (Jupiter) which procedure holds good for Mars and Saturn as well. In fig. (6.6) the heliocentric longitude of Jupiter with respect to the zero-point of Hindu zodiac namely the first point of Aświnī asterism is given by the angle $A'SJ$ (Note that the geocentric direction EA and the heliocentric direction SA' are almost parallel because of the great distance of Aświnī. The geocentric direction of Jupiter is given by the angle AEJ.

Now $AEJ—A'SJ=E\ J\ S$,
i.e. the difference between the two directions is the angle EJS which is therefore the *śighraphala* correction to be effected to the heliocentric direction to get the geocentric direction. Here in this case J is on the right-hand side of ES, so that the correction is positive (on the left-hand side of ES, the correction would be negative). In other words the correction will be positive or negative according as $180° < m < 360°$ or $0° < m < 180°$. Here 'm', called the *śighra* anomaly, is equal to $A\ E\ S—A'\ S\ J=$ geocentric direction of the Sun minus heliocentric longitude of the planet. The Sun is spoken of as the *śighrocca* therefore with respect to the superior planets, bearing the analogy of the *mandocca* in finding the equation of centre.' m' the argument, which was called the *manda-kendra* or the argument from which the equation of centre was computed, there the situation being,

heliocentric longitude of the planet—longitude of the aphelion or *mandocca* =*manda kendra.*

Here, in the case of *śighraphala,* 'm' is given by geocentric longitude of the Sun minus heliocentric longitude of the planet. The words *manda* and *śighra* will be seen to have etymological significance that they have slower or faster motion as compared with the planet. Hence we have shown the planet ahead or behind respectively in the two cases. The *mandaphala* was negative when $0° < m < 180°$ and positive when $180° < m < 360°$, so that in both the cases, we find the planet attracted towards the *ucca* (whether *śighrocca* or *mandọcca*). Hence Bhāskara says as also *Sūryaisiddhānta,* that the *ucca* attracts the planet towards it. In particular Bhāskara says "*ucco hi ākarṣako bhavati*".

Bhāskara has a significant statement: "*kakṣā-madhyaya tiryagrekha prativṛtta sampate, madyaiva gatiḥ spaṣtā, param phalam tatra khetasya*". "The *mandaphala* or *śighraphala* will be maximum positively or negatively at the points of intersection of the eccentric circle with the line passing through the centre of the *kakṣāvṛtta* or the deferent." This is

clear in fig. 6.3 in the context of the *mandaphala* in the position p' of the true planet where the angle M A P=90° the maximum equation of centre being equal to PO the radius of the epicycle otherwise called *antyaphala*. Similarly, if we draw the eccentric circle in the case of the *śighraphala* also (the same figure holds good in this case also) we can see that the *śighraphala* also will be maximum at that spot. This fact is also borne out in the heliocentric fig. 6.6 (the heliocentric figure is not drawn in the case of the equation of centre because in modern astronomy, we have the ellipse whereas in Hindu astronomy we do not have such an ellipse but only the same epicyclic or eccentric theory) where when J is at the points A or B, the angle E J S will be a maximum because

$$\frac{\sin EJS}{a} = \frac{\sin JES}{R} \therefore \sin EJS = \frac{a}{R} \sin JES$$

$$\therefore \quad EJS \text{ will be maximum with } J\ E\ S = 90° \quad \ldots \quad \ldots \quad (7)$$

Bhāskara's verse quoted above says further that the *madhyagati* or the velocity of the mean planet in the case of the equation of centre and that of the *mandasputagraha* in the case of the *śighra* correction will be equal to the velocity of the *mandasphuṭagraha* or the planet corrected for the equation of centre and the true planet corrected for *śighraphala* in the two cases respectively. This is easy to say from equations, already discussed, where, in the first case the velocity of the *mandocca* or the aphelion almost being negligible.

$(PQ \sin m)$ when $m=0$ will be zero. Hence the difference in the equation of centre which is maximum at that point will be zero (the criterion of maximum). Similarly in equation 7, $\triangle\ (a \sin J\ E\ S)$ When $J\ E\ S = 90°$, is equal to zero, (again the criterion of the maximum). In the case of the equation of centre, because we took arc $PT = QL$ approximately, the *mandagati* or the velocity of the *mandasphuṭa-graha*$= \triangle\ (PQ \sin m) = PQ \cos m\,\delta m$. This is given by Bhāskara in verse 37 of *Spaṣṭādhikāra*, when $M_1 + E_1 = M_2$, i.e. longitude of the mean planet plus equation of centre is equal to the longitude of the *mandasphuṭagraha*. But $\triangle M_2 = \triangle\ (M_1+E_1) = \triangle\ M_1 + \triangle\ E_1 = 0+0$ because the mean motion $\triangle$ is constant and $\triangle\ E_1 = 0$ because E_1 is maximum. Similarly $M_1+E_2=M_2$ or the longitude of the *mandasplutagraha*+*śighraphala*=true planet.

$$\therefore \triangle\ (M_2) = \triangle\ M_1 + \triangle\ E_2. \text{ When } \triangle\ E_2 = 0 \text{ because } E_2 \text{ is a maximum,}$$
$$\triangle\ M_2 = \triangle\ M_1$$

i.e. the true motion is equal to the motion of the *mandasphuṭagraha* as stated by Bhāskara.

Śighragatiphala—from equation (7)

$$\sin EJS = \frac{a}{R} \sin JES$$

$$\therefore \triangle\ (\sin EJS) = \frac{a}{R} \triangle\ (\sin JES) = \textit{śighragatiphala} \text{ as it is called. But } JES \text{ being}$$

the elongation of the true planet and this being not measured in practice by the Hindu astronomers, Bhāskara derives the *śighragatiphala* in an ingenious way, which

exhibits his genius. This *śighragatiphala* is very important because we have got to know when the planet retrogrades.

Before we seek to find the *śighragatiphala* let us take up the procedure laid down to rectify the inferior planets Mercury and Venus. We take Venus and the procedure is the same with respect to Mercury also.

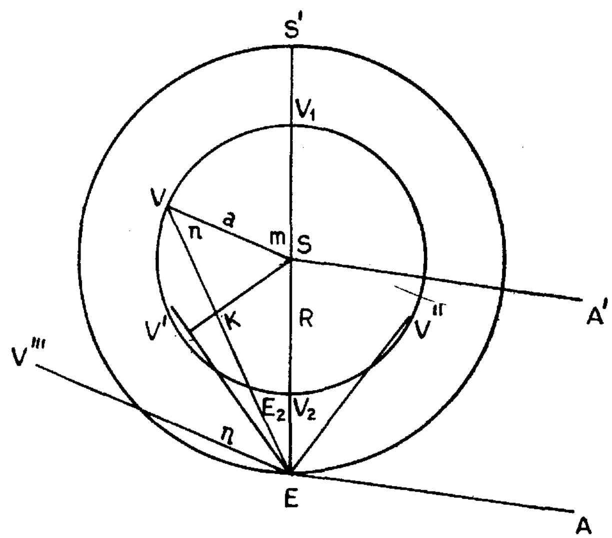


Fig. 6.7 Correction for inferior planets Mercury and Venus.

E = Earth; S = Sun, V = Venus.
Take $SV = a$ and $SE = R$. EA is the geocentric direction of the Hindu Zero-point A; SA' is the heliocentric direction of the same point. V' = position of V at max. elongation. 'm' is here the *śighra* anomaly.

Since, it was construed that the *madhyagraha* of the inferior planet is the Sun, inasmuch as the inferior planet oscillates about the mean position of the Sun as seen from the Earth, and since V the heliocentric Venus was construed as the *śighrocca* of Venus, to accord with the method postulated with respect to the superior planets.

Longitude of *śighrocca*—longitude of the mean planet

$$= \textit{śighrakendra} = m \text{ or } A'\hat{S}V - A'\hat{S}S' = S'\hat{S}V = m.$$

From the triangle ESV, $\dfrac{a}{K} = \dfrac{\sin S\hat{E}V}{\sin E\hat{S}V}$

$$\therefore \text{Sin } S\hat{E}V = \frac{a}{K} \sin E\hat{S}V = \frac{a}{K} \sin m.$$

This is the same as we got in the case of a superior planet. Hence $S\hat{E}V$ is termed here as the *śighraphala,* which is no other than the elongation of the planet. This will

be evidently a maximum when EV' is tangential to the inner circle. Then sin $S\hat{E}V$ $= \frac{a}{R} =$ a constant so that the maximum *śighraphala* will be equal to $\sin^{-1} \frac{a}{R}$ which is the same as the maximum elongation. From the table shown before, under the caption 'Elements of the Solar system' taken from Ball's *Spherical Astronomy* in the case of Mercury the maximum elongation of Mercury is $\sin^{-1} .387 = 22°48'$ and in the case of Venus $\sin^{-1} .7233 = 47°12'$ (ofcourse taking the orbits to be coplanar circles.)

$$\text{Since } A\hat{E}S + S\hat{E}V = A\hat{E}V,$$

therefore, the mean longitude of the Sun plus the *śighraphala* equals the geocentric longitude of the planet (Venus or Mercury). K is calculated as was done in the case of the superior planets. In the case of the inferior planets, since they move faster than the Earth, or what means the same, they move faster than the Sun, relatively speaking, so the heliocentric Venus is termed *śighrocca,* justifying the word *śighra.* As per the word *ucca,* it has a double significance: (1) when V occupies the position V_1 in Fig. 6.7, Venus will be farthest from the Earth; under this perspective when Venus is at V_2 it is nearest the Earth, but the word *ucca* has no significance here; (the word *śighranīca* is not used in the Hindu astronomical works); (2) more than the first significance, since in the equation of centre we said longitude of *graha*-longitude of *mandocca*=*mandakendra,* similarly here heliocentric longitude of Venus (or its *śighrocca*)—longitude of the mean Sun (i.e. mean planet)=*śighrakendra.* Thus the word *ucca* is significant so far as its position gives us the mean anomaly or the *śighra* anomaly (the word anomaly here is an odd usage).

Thus in the case of an inferior planet, its elongation is the *śighraphala.*

The Hindu epicyclic theory also leads us to the value *śighraphala* $= \frac{a}{K} \sin m,$ as in the case of the superior planets. However in the case of the superior planets, the epicycle corresponds to the orbit of the Earth, and the circle got rotating the point E about the centre of the epicycle will be the orbit of the planet. The centre of the epicycle here coincides with the point S of the heliocentric figure 6.7. Looking at the dimensions of the epicycles both with respect to the superior and inferior planets, and looking at the table cited before from Ball's *Astronomy*, it is clear that the *śighraphala* is no other than the correction required to reduce the heliocentric longitude to the geocentric in both the cases of the superior and inferior planets.

Śighragatiphala: As mentioned before, this is a very important concept, which gives us the knowledge when a planet retrogrades. Bhāskara says in verse 39 Chapter-II *Gaṇitādhyāya*

$$\delta l - \frac{H \sin (90—E)\, \delta m}{K} = \delta S,$$

where δl is daily mean motion of the *śighrocca*, δm=daily mean motion of the *śighra* anomaly, E=*śighraphala*, and δS=true geocentric motion of the planet. If δS is negative the planet is in retrograde motion. K is the *śighrakarṇa* mentioned before. From fig. 6.6, *sphuṭagati* or the true daily motion of the planet Jupiter is $\triangle(A\hat{E}J) = \delta S$.

$$\text{But } \triangle A\hat{E}J = \triangle A\hat{E}S - \triangle J\hat{E}S.$$

$\triangle A\hat{E}S$ is called the *śighrabhukti* of Jupiter or the true daily motion of the *śighrocca* of Jupiter or what is the same the true daily motion of the Sun. Hence, to find $\triangle AEJ$, we have to find $\triangle(J\hat{E}S)$, because $\triangle AES$ is known. In fig. 6.6, we have connoted $J\hat{E}S$ as $\hat{n}$, whereas m, i.e. the angle $J\hat{S}M$ in the figure is called the *śighrakendra*, this angle $\hat{n}$ is called *sphuṭa śighrakendra*. In this context the verse given by Bhāskara is very significant, as well as its proof which is highly complicated and as such reflects on his genius. The verse deserves to be quoted and is

Phalāṃśa khāṅkāntara śiñjinighnī,
Drāk-kendra bhuktiḥ śrutihṛt viśodhyā
Swaśighra bhukteḥ, sphuṭakheta bhuktiḥ
Seṣam ca vakrā viparīta śuddhau

Meaning:—phalāṃśa=the degrees of the *śighraphala*, *khāṅka*=90° (*kha*=*o*, *aṅka*=9; in Hindu numbering we proceed from the right to the left as is said *aṅkānām vāmato gatiḥ*, so that, the number becomes not 09 but 90°). Thus *phalāṃśa khāṅkāntara* means $(90°—E_2)$ where E_2 is the *śighraphala*. The word *śiñjinī* means the Hindu sine. We are asked therefore to multiply (the word *ghnī* means being multiplied) H Sin $(90—E_2)$ by *drāk-kendra bhukti*, i.e. the daily motion of the *śighrakendra*, i.e. δm. So we get $H \sin (90—E_2)\ \delta m$. This is directed to be *śrutihṛt*, i.e. to be divided by the *karṇa* K. Thus far we have $\dfrac{H \sin (90—E_2)}{K}$. This is directed to be *viśodhyā*, i.e. subtracted from *svaśighra bhukti*, i.e. the daily motion of the *śighrocca*, i.e. of the Sun. The result will be δS, i.e. the true daily motion of the planet given by

$\triangle\ (AEJ)$. So, $\delta S = \delta l — \dfrac{H \cos E_2\ \delta m}{K}$, where δl is the daily motion of the Sun.

Here one point is to be noted. After getting the *manda-sphuṭagati* or the daily motion of the planet rectified for the equation of centre (let us call this M_1) $M_1+E_2=S$, where E_2 is the *śighraphala* equal to $\dfrac{a \sin m}{K}$ as obtained before, and S the true planet.

$\delta s = \delta M_1 + \delta E_2$. Here δM_1 could be got easily being the daily motion of the planet rectified for the equation of centre. In fact, $\delta M_1 = \delta M + \delta E_1$ where δM is the mean daily motion of the planet and δE_1 is the daily variation of the equation of centre. δM is known and $\delta E_1 = \delta\ (a \sin m) = a \cos m\ \delta m$, which is known easily. (Note

here that, we do not effect what is called *karṇānupāta* in the case of the equation of centre, i.e. we do not divide by K. Since the equation of centre is small, we effect this *karṇānupāta* in the case of the *śīghraphala*, because this *śīghraphala* is far greater than the equation of centre).

Coming to the point, since

$M_1+E_2=S$, δM_1 being known easily, is it not enough to get δE_2 or $\delta \dfrac{(a \sin m)}{K}$?

Bhāskara says significantly that in $\dfrac{a \sin m}{K}$ both m and K are variable from day to day, and therefore to get the differential of $\dfrac{a \operatorname{Sin} m}{K}$ is not easy (Remember here though Bhāskara knew that δ (sin m) $=\cos m \ \delta m$ which formula he used very often, he was not aware of the formula $\delta \dfrac{(u)}{v} = \dfrac{v\,\delta u - u\,\delta v}{v^2}$ of modern calculus. Bhāskara was five centuries older than Newton and to have gauged that δ (sin m) $=$ cos m δm was indeed creditable on his part). So Bhāskara says "*mahā matimadbhiḥ kendragatiḥ eva spaṣṭi kṛtā*", i.e. great intellects rectified 'm' of fig. 6.6 instead of seeking $\delta \dfrac{(a \sin m)}{K}$ where m and K are both variable. In other words, they sought to find 'n' which is called *sphuṭakendragati*, in the place of finding δm called *madhyakendra gati*. (Incidentally note that he was paying a compliment to the genius of Brahmagupta by using the word 'great intellects').

Now we shall seek the proof of the formula given by Bhāskara, using the heliocentric figure first and then understand his own proof in the eccentric theory.

From fig 6.6 $K \cos n — R \cos m= a$ (using the elementary trigonometric formula in a triangle namely b bos $C+C \cos B=a$. Taking differentials from the above,

$$—K \sin n \ \delta n+\cos n \ \delta k+R \sin m \ \delta m=0 \quad .. \quad .. \quad .. \quad (8)$$

because a is a constant. But we have

$$K^2=R^2+a^2+2\,R\,a \cos m. \text{ So that } 2K\,\delta K=—2\,R\,a \sin m \ \delta m. \quad .. \quad (9)$$

Eleminating δk between (8) and (9)

$$—K \operatorname{Sin} n\,\delta n — \frac{Ra \sin m\,\delta m \times \cos n}{K} + R \sin m\,\delta m=0.$$

$$\text{i.e. } K \sin n\,\delta n = R \sin m\,\delta m \left(1 — \frac{a}{K} \cos n\right)$$

$$= R \sin m\,\delta m \ \frac{(K — a \cos n)}{K}$$

But $K - a \cos m = R \cos E$

$$\therefore \ \delta n = \frac{R \sin m\, \delta m \times R \cos E}{K^2 \sin n} \quad \text{But } R \sin m = K \sin n$$

$$\therefore \ \delta n = \frac{R \cos E\ \delta m}{K} = \frac{H \cos E\, \delta m}{K}$$

as given by Bhâskara. It is worth-while for the reader to go into the argument adduced by Bhâskara (in his own words).

In the above, we have given a proof based on the modern heliocentric figure just to show how Bhâskara could go into intricate mathematics. Before we see his own proof, it yet remains for us to note the treatment of the minor planets Mercury and Venus.

We have seen that the true geocentric longitude of the inferior planet is got by adding to the *mandasphuṭagraha* or the mean planet rectified for the equation of centre, the *śighraphala* which is no other than the elongation of the planet given by $\frac{a}{K}$ sin m.

Next the question arises, as to whether the procedure laid down to get the *śighragatiphala* in the case of the inferior planets also is the same as that laid down in the case of the superior planets. There is a slight difference, however, though the formula $\frac{H \cos E\ \delta m}{K}$ holds good here also. There difference is with respect to the *sphuṭa-kendra,* The *sphuṭa-kendra* in this case (Ref. Fig. 6.7) is the angle between the heliocentric direction of Venus namely SV or EV and the geocentric direction of V namely Ev, marked equal to n in the figure since in this case also

$m + E_2 = n$ as in fig. 6.6, E_2 of course, having a different connotation, and since E_2 here also has the same formula namely $\frac{a}{K}$ sin m, the same mathematics holds good here also to get the true daily motion of the planet.

Now we shall give Bhâskara's proof with respect to the *śighragatiphala,* formerly proved and obtained as $\frac{H \cos E\ \delta m,}{K}$ taking the heliocentric fig. 6.7. Now we shall trace the steps of Bhâskara from his eccentric fig. 6.8, given below, and ascertain the veracity of his statement that the rectified *kendragati* δn is equal to $\frac{H \cos E\ \delta m.}{K}$

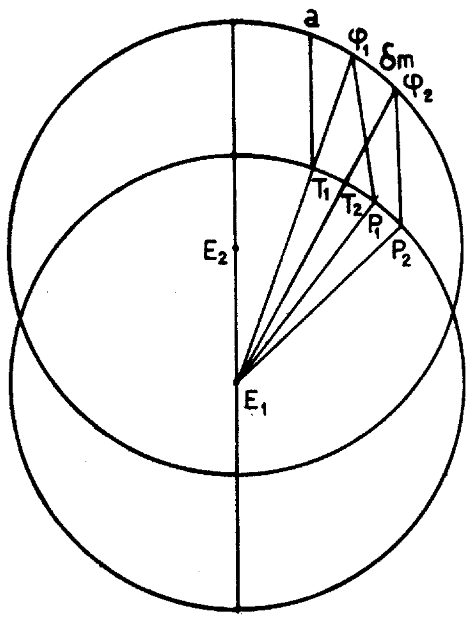


Fig. 6.8 Bhāskara's proof with respect to *śighragatiphala*

In the fig 6.8 above P_1, P_2 and Q_1, Q_2 are the positions of the mean planet in the *kakṣā-vṛtta* and *prativṛtta* on two consecutive days. Let T_1, T_2 be the true planets on the two consecutive days. Evidently P_1T_1, and P_2T_2 are the value of the *śighraphala* on the two days. Draw a parallel through T_1 to E_1A_2 to meet the *prativṛtta* at a. $A_1T_2—A_1T_1=$ the difference of the *sphuṭakendras* on the two days, which is equal to T_1T_2 is called *sphuṭakendragati*. Since *śighra—sphuṭagraha=sphuṭakendra, śighragati—sphuṭagrahagati= sphuṭa-kendragati* or what is the same *sphuṭagrahagati=śighragati—sphuṭakendragati*. Now the problem is to find $P_2T_2—P_1T_1$ which is called *sphuṭakendragati* (as named previously). It will be noted that *madhyakendragati* is equal to Q_1Q_2 in Fig. 6.8. In the figure P_1T_1 is the *śighraphala* on the first day which is equal to a Q_1, P_2T_2 is the *śighraphala* on the second day.

In the figure considering Q_1Q_2, i.e. δm as an increment in the *śighraphala* aQ_1 (in the figure it may not appear so. δm is small compared to aQ_1) equal to $\frac{a}{K}$ Sin $m=\sin E$ we are hence required to find $\sin(E+\delta m)-\sin E$ where δm is small compared to E.

$\sin(E+\delta m)=\sin E\cos\delta m+\cos E\sin\delta m$. Put $\cos\delta m=1$ and $\sin\delta m=\delta m$
$\therefore\ \sin(E+\delta m)=\sin E+\cos E\ \delta m$.

Since this $\cos E\ \delta m$ is on the *prativṛtta*, we have to reduce it to *kakṣāvṛtta* by multiplying by R and dividing by K. Hence the required quantity

$$=\frac{R\cos E\ \delta m}{K}=\frac{H\cos E\ \delta m}{K}$$ as is given by Bhāskara.

In this context, we find Bhāskara criticizing Lalla for having used the word *āśu-cāpa*, by which Lalla meant *āśu-phala-cāpa* and not *āśu-kendra-cāpa* as misread by Bhāskara. So the credit may also go partly to Lalla, who was indeed a great astronomer contemporary to Brahmagupta.

It remains for us to establish a correspondence between Bhāskara and modern astronomy in this point, because, we have to assure ourselves that the Hindu method of finding at what point a planet retrogrades is also correct. Assuming coplanar concentric circles,
let S=Sun, E=Earth, J=Jupiter, m=*śighra* anomaly, Ev and Ev' drawn tangents to ES and EJ. Let angle $V\hat{E}V''=\theta$. Let Jupiter appear stationary as viewed from the Earth in this position, so that it is the beginning point of retrograde motion. Let $E\,S\,J=\phi$ and $EJS=\xi$. Let u and v be the velocities of the Earth and Jupiter (linear) let a and R be the orbital radii as before. Since the relative velocity of Jupiter with and respect to the Earth is zero,

$$u \cos \theta + v \cos \xi = 0 \therefore \frac{u}{v} = \frac{-\cos \xi}{\cos \theta}.$$

But from triangle ESJ, $R \cos \phi + K \cos \theta = a$ and

$$a \cos \phi + K \cos \xi = R \quad \therefore \frac{\cos \xi}{\cos \theta} = \frac{R - a \cos \phi}{a - R \cos \phi}$$

$$\therefore \frac{-u}{v} = \frac{R - a \cos \phi}{a - R \cos \phi}. \text{ So that } \cos \phi = \frac{au + Rv}{av + Ru}.$$

$$\text{But } m = 180 - \phi \quad \therefore \cos m = -\left(\frac{au + Rv}{av + Ru}\right)$$

Here *spaṣṭagati* is equal to zero. Hence in the formula,

$$\textit{spaṣṭagati} = \textit{śighragati} - \frac{H \cos E\ \delta m}{K},$$

$$\textit{śighragati} = \frac{H \cos E\ \delta m}{R}.$$

The angular velocities of the Earth and Jupiter are respectively $\frac{u}{a}$ and $\frac{v}{R}$ so that the Sun's apparent velocity also is u/a.
δm=*kendragati*=Sun's apparent velocity minus Jupiter's heliocentric velocity.

$$= \frac{u}{a} - \frac{v}{R}.$$

$$\therefore \textit{śighragati} = \frac{u}{a} = \frac{H \cos E}{K}\left(u/a - \frac{v}{R}\right)$$

$$\therefore \frac{u}{a}\left(\frac{H \cos E - 1}{K}\right) = \frac{H \cos E}{K} \times \frac{v}{R}$$

$$\therefore \frac{u}{a}\left(\frac{H \cos E - K}{K}\right) = \frac{H \cos E}{K} \times \frac{v}{R}.$$

But $H \cos E = R \cos E$ (Hindu Trigonomety) $= R \cos \xi$ (here ξ standing for E) and $R \cos \xi - K = - r \text{ Cos } \theta$

$\therefore u \cos \theta + v \cos \xi = 0$ which accords with the modern method as derived before. From this follows

$$\cos m = -\left(\frac{au + Rv}{av + Ru}\right) \text{ as said before.}$$

Substituting the relative values of a and R, we have the respective values of m for each planet, when it becomes stationary. We could more easily use equation $u \cos \theta + v \cos \xi = 0$, noting $\theta = m - \xi$. We shall next make here some points of observation pertinent to the context.

We have $M_1 + E_1 = M_2$ and $M_2 + E_2 = S$ where M_1 is the original mean planet, E_1=equation of centre, M_2=*mandasphuṭagraha*, E_2=*śighraphala*, S= true planet.

$\delta M_2 + \delta E_2 = \delta S$, which means *mandasphuṭagati* plus *śighragatiphala* (not *śighraphala*)=*spaṣṭagati*. Now let E_2 be maximum, so that $\delta E_2 = 0$, Then $\delta M_2 = \delta S$. This means that at the points B and C of the heliocentric figure 6.6, the *śighraphala* is maximum and the *mandasphuṭagati* is equal to the true motion. This line BC corresponds to the line mentioned by Bhāskara in the verse.

Kakṣā madhyagatiryak-rekhā prativṛtta-sampāte,
Madhā eva gatiḥ spaṣṭā, param phalam tatra khetasya

This is the line drawn through the centre of the *kakṣāvṛtta* to cut the *prativṛtta* in the eccentric figure.

(2) Another point of observation is that since

$\delta M_2 + \delta E_2 = 0$ means that the true velocity of the planet is zero. So δM_2 must cancel δE_2 when the planet is stationary. In Fig. 6.6 $E_2=0$ at $\acute{S}$; it becomes positive as J moves from S' to C in the clockwise direction (this is so because we have kept ES in a constant direction and as S has a greater positive velocity, J takes a clockwise motion). Then E_2 will have a positive maximum at C. From C to the point diametrically opposite to S, the positive E_2 becomes zero. From this diametrically opposite point as it moves clockwisely to B, it grows negatively to a maximum at B. As J then moves from B clockwisely, the negative maximum gradually gets nullified at S'. In other words, in the arc $C S'$ taken anticlockwise, since E_2 increases positively, δE_2 will be positive and this δE_2 becomes zero at C. Since δM_2 is always positive, $\delta M_2 + \delta E_2 = 0$ in the arc $S'C$. Now δE_2 becomes negative as J proceeds clockwisely to B. At some point in between J on this arc and the point S', $\delta E_2 + \delta M_2$ becomes zero. This means that as a superior planet is near opposition it becomes retrograde. Similarly on the arc $S''B$ taken clockwise, in between S'' and B, $\delta M_2 + \delta E_2$ will be zero, and thereafter becomes positive. Hence on the arc $C'D'$, where C' and D' are symmetrically situated with respect S'', the superior planet is retrograde.

In the case of the Inferior planets (Ref. Fig. 6.7) they reach a maximum elongation on either side of the Sun. Suppose the Sun is in advance, so that the inferior planet will be a morning star; here the planet retrogrades to a maximum elongation and then after sometime, becoming stationary, the elongation decreases to zero. Thereafter the planet overtakes the Sun and becomes visible in the western sky as an evening star. The planet now has a direct motion, and attains a maximum elongation on the right of *ES* in fig. 6.7. Then the planet becomes retrograde. Thus the Inferior planet is retrograde on the arc V' V'' taken anticlockwise and direct on the arc V'' V' taken also anticlockwise. While at V_1 and V_2 it sets in they rays of the Sun. This setting in the rays of the Sun either for the Inferior planet or the Superior planet, is called heliacal setting and emerging from the rays of the Sun is called heliacal rising. It is easy to see that a superior planet sets in only in conjunction whereas an inferior planet sets both at the superior and inferior conjunctions. Which means that it sets both in the East and the West. The superior planet on the other hand sets only in the West heliacally and goes round the Sun the entire circle or the entire synodic period. The period of heliacal setting in the case of an inferior planet at the inferior conjunction is far longer than that at the superior conjunction, because the planet and the Earth are moving in the same anticlockwise direction at the inferior conjunction, whereas at the superior conjunction, their velocities add.

In conclusion, it may be mentioned that the data given by Bhāskara with respect to the stationary points, and heliacal rising and setting accord very well with the data given in modern astronomy. This is indeed remarkable, because the Hindu astronomers using the epicyclic and eccentric theories, and under the explicit geocentric theory (which is in fact not at all geocentric as the mathematics on the previous pages has revealed to us) achieved much more than could be expected of them at that distant past as long ago as Āryabhaṭa's time, many a century before Copernicus. In the wake of the mathematics expounded in this paper, nobody has the right to say that the Hindu theory was geocentric. What Copernicus achieved was, to read in between the mathematics and discover the heliocentric theory, which was formerly implicit.

7

ECLIPSES, PARALLAX AND PRECESSION OF EQUINOXES

S. D. SHARMA

ECLIPSES

Since remote antiquity occultations of heavenly bodies attracted the attention of man and inspired him to find the time of recurrence of such events. The occultations of the Moon with *yogatārās* (junction stars or the identifying stars) of asterisms on its path (lunar zodiac) and conjunctions of other planets too with stars, or any other planet, likewise generated great interest. The most important occultation of the Moon with the Sun resulting in solar eclipse and of Moon itself, by the Earth's shadow leading to the lunar eclipse, might have proved very fascinating events. The earliest attempts to know their recurrence timings were based on determination of empirical cycles by observing colours of eclipses and identifying them as brown colour shading or dark colour shading etc. These were the attempts to find repetition cycles of eclipses of the same kind (colour). In fact, the colour of an eclipse depends upon the elongation of nodes of lunar orbits w.r.t. Sun which determines how intense (brown dark or deep dark etc.) the eclipse will be as a result of relative gradations in extents of overlapping. In ancient civilizations like China, Babylon, etc. records of eclipses had been kept. Ptolemy had a record of eclipses from 747 B.C. to 150 A.D. These records on analysis gave metonic cycle. It is believed that the Chinese might have this cycle earlier. In India, in early Vedic times there were periods determined on the basis of such observational records over centuries. We find a period of 20000 days,[1] and it is clear that

2000 days = 56 lunar years + 3 months
= 675 lunations = 3 (18 years — 9 m)
= 3 Periods of lunar node (Rāhu).

Thus the above mentioned cycle is justified. Early Vedic Aryans distinguished 3 different colours of eclipses (solar and lunar separately), i.e. black, red and white and tried to recognize periods of eclipses with specific colours.[2] On dividing the above figure (2000 days) by the number of colours (3) one gets the period of occurrence of eclipses of the same colour. This is almost equal to the period of Rāhu or Ketu (the ascending and descending nodes of lunar orbit). The Jaina texts like *Sūryaprajñapti*[3] mention five colours of eclipses, which is an advancement over the observations of *Vedāṅga Jyotiṣa* tradition. There is mentioned a cycle of 6 months.[4] We know that

675 lunations = 3 Chaldean saros + 6 months.

Thus the period of 6 months is also one of the shortest cycles, easily conceivable in early studies of solar and lunar eclipses.

In the *Vedāṅga Jyotiṣa* we do not find algorithms for computing eclipses, but there is a reference to a phenomenon of colouration which is referred to as *Vyatīpāta yoga*.[5,6] This was the phenomenon (of colouration of Sun and Moon) for predictions of which, there were developed some methods in Jaina traditional astronomy.[7] Reference to this phenomenon occurs in *Paitāmaha Siddhānta* also.[6] In Siddhāntic texts later, this phenomenon got interpreted as the occurrence of equality of declinations of the Sun and the Moon. It may be remarked that occurrence of *Vyatīpāta yoga* later got connected with a general form equality of declinations (*Krānti sāmya*) irrespective of their signs (see appendix). The methods of computing timings of this phenomenon developed from Vedic times and we find detailed methods of computing the occurrence of this in Jaina texts too. *Jyotiṣa Karaṇḍaka*[7] gives detailed methods of computing its reoccurrence in five year *yuga* of Vedic and post-Vedic tradition. But there were no other *yogas* completing the list of 27 as found in later astronomical texts. Almost all the theoretical treatises after Āryabhaṭa have dealt with the problem of *krānti sāmya* (equality of declinations of Sun and Moon) in details.

The Jaina canonical text has reference to two types of Rāhus, one of them being responsible for waxing and waning of the phases of Moon[8] (1/15th part of the lunar disc every day) while the other one was considered responsible for eclipses. There are five categories of this Rāhu depending upon the direction of 1st and last contacts and nature of eclipses[9] (like being partial, total or annular). There are no records preserved in the literature on the basis of which they inferred the cycles but it was concluded that the Parva Rāhu (responsible for eclipses) covers[10] the Sun or Moon at least once in six months and excellently Moon in 42 months and Sun in 48 years as discussed earlier. Jainas had records of 5 colours and concluded these cycles on the basis of these colours. The mathematical analysis of these findings is discussed by Sharma et al.[11] using number of theoretical methods. In brief: for lunar eclipse 42 eclipse months $\simeq$ 41 lunations and for solar eclipse 45 years $\simeq$ 48 eclipse years.

In later texts, after Vedic and Jaina canonical literature, we see the development of computational algorithms to predict eclipses. The notion of Rāhu got developed and the lunar ascending node was named after the same.

In the *Pañcasiddhāntikā* of Varāhamihira, *Vasiṣṭha* and *Romaka Siddhāntas* give algorithms for computing eclipses using the longitudes of Sun and Moon. The rules for computing eclipses are as follows :—

Rule I

(1) (A) For the lunar eclipse, find the difference D in longitudes of the near node and the Moon. If this is less than 13° lunar eclipse will take place, when she is in opposition to the Sun.

(B) (a) Time* of the beginning of eclipse is given by :

$$T_1 = T - 3/20\sqrt{169 - D^2}$$

*Here the time is given in hours and minutes; if the time is expressed in *nāḍikās* the factors preceding the root should be 3/8.

(b) Time of the ending of eclipse is given by :
$T_2 = T + 3/20\sqrt{169-D^2}$
where T is the time of opposition.

Rule II

(2) (A) Let the latitude of the Moon at that time be β in minutes of arc. If $\triangle\lambda$ is the hourly change in elongation of the Moon with respect to Sun, then the time for the beginning of eclipse is given by :

$$T_3 = T - \sqrt{55^2-\beta^2/\triangle\lambda} \quad \text{(I)}$$

Time for the ending of eclipse is given by:

$$T_4 = T + \sqrt{55^2-\beta^2/\triangle\lambda} \quad \text{(II)}$$

(B) $T' = T \mp 21/5\triangle\lambda\sqrt{25-\beta^2}$ gives beginning and end of partial maximum or total eclipse. (III)

Here it is clear that when the difference in longitudes of the node and the Moon is 13°,+ the latitude of the Moon is taken to be 55′ which means that near the node the latitude is assumed to change 55′/13 minutes per degree. The sum of radii of Sun and Moon is (from I) :

$$r_m + r_s = 55'$$

Their difference (from III) is

$$r_s - r_m = 21'$$

$$\therefore \quad r_s = 38' \qquad r_m = 17'$$

which are taken to be constants.

The middle of eclipse is at T, the duration is zero if $r_s + r_m = \beta$.

The results are based on mean motions of the Sun and the Moon as hourly variations in longitudes are neglected.

The first rule is more primitive as it ignores the latitude of the Moon. *Pauliśa-siddhānta* discusses the method for computing solar eclipses. Here the parallax in longitude is converted to the time correction for conjunction (see the discussion parallax Eq. (1) later on). *Romaka-siddhānta* gives an improved version for computing solar eclipse.[12] It is this text which uses *tribhona-lagna* (nona-gesimal) for the first time. This very text gives parallax correction in latitude (i.e. the *natisaṃskāra*) in addition to parallax correction in longitude.

The *Sūrya-siddhānta* in *Pañcasiddhāntikā* of Varāhamihira gives a better and more refined method for computing solar eclipse and uses far better constants. Like in *Romaka*, it uses true motions and consequently more correct parallaxes and angular diameters. The true motion of the Moon at the time of eclipse is used instead of true

daily motion. Parallax-corrected conjunction time is computed using parallax-corrected longitudes. A separate chapter is devoted for graphical representation of eclipses. To mark the points of 1st and last contacts, the Moon's position is to be fixed with respect to east-west of the observer. For this purpose, two corrections *ākṣa valana* (depending upon latitude of the place of observation) and *āyanavalana* (depending upon the Moon's *ayana* w.r. to equinoxes) are to be applied to the east west point. But in computing *ākṣavalana* versed sine is used instead of sine of the hour angle which is a mistake as pointed out by Bhāskarācārya II. Vasiṣṭha does not give *āyana valana*, but the *Sūrya-siddhānta* gives fairly accurate formula. The *Romaka-siddhānta* is silent about directions of 1st and last contacts.

The *Āryabhatiya* and *Mahābhāskarīya* give same method of computing parallaxes, angular diameters and *valana*. These compute parallaxes separately for the Sun and Moon and then take the difference. In the case of the Moon the same is taken in her own orbit instead of in ecliptic. It is interesting to note that *Mahābhāskarīya* uses parallax in computing lunar eclipse also, but it does not result in any difference in final figures.

ALGORITHM FOR COMPUTING ECLIPSES IN PRESENT RECENSION OF SURYA-SIDDHANTA

Having surveyed the developments historically, let us discuss in brief the working algorithm for computing eclipses according to the present version of the *Sūrya-siddhānta,* then we would like to comment on the successes and failures of these methods in the light of the equations of centre being applied to the Sun, other constants being used and the theoretical formulations involved therein. Before starting the actual computations, one should first check the possibility of occurrence of eclipse. It may be pointed out that in Indian tradition, the ecliptic limit was taken to be 14° elongation of Rāhu at the moment of syzygies. The limit is same for lunar and solar eclipse; because it was computed using mean radii of Sun and Moon and the parallax was neglected.

Lunar Eclipse

At the time of ending moment of *purṇimā* (full moon) one should compute the true longitudes of Sun, Moon and ascending node (Rāhu). The apparent disc of the Sun in lunar orbit is calculated using their mean diameters. Also the cross section of earth's shadow in the lunar orbit is computed. From the diameters of the overlapping bodies, and latitude of the Moon, position of Rāhu, one can easily infer whether the eclipse will be complete or partial. The half of the time of eclipse $T_{\frac{1}{2}}$ *(sthityardha)* is given by

$$T_{\frac{1}{2}} = \frac{60}{V_m - V_s}\sqrt{\left(\frac{D_1 + D_2}{2}\right)^2 - \beta^2}\ \textit{ghaṭis}$$

where V_m = daily velocity of Moon, V_s = daily velocity of Sun, β = latitude of moon and D_1, D_2 stand for angular diameters of overlapping bodies (Earth's shadow and

Moon in case of lunar eclipse). Thus the beginning (*sparśa* or 1st contact) and ending (*mokṣa* or last (4th) contact) are given by

$T_0 \mp T_{\frac{1}{2}}$ where T_0 is the time of opposition.

Similarly half of the time of full or maximum overlap *(vimardārdha)* will be given by

$$T'_{\frac{1}{2}} = \frac{60}{V_m - V_s} \sqrt{\left(\frac{D_1 \sim D_2}{2}\right)^2 - \beta^2} \text{ ghaṭis.}$$

and $T_0 \mp T_{\frac{1}{2}}$ will be the moments of beginning and ending of full overlap *(vimarda)*. (These are the timings for *sammīlana* and *unmīlana* in traditional terminology which indicate the positions when the two bodies touch internally). Thus one gets the 3rd and 4th contacts also.

In order to have better results, the positions of the Sun, Moon and Rāhu are computed at the instant of the middle of the eclipse and using these the required arguments are recomputed and again the *sthityārdha* and *vimardārdha* are computed. The procedure is recursive and is expected to improve the results. The *Sūrya-siddhānta* gives also the formulae for eclipsed fraction (maximum and instantaneous) which are easily provable on the basis of the geometry of the eclipse phenomenon. Also it gives the formula for remaining time of eclipse if the eclipsed fraction is given after middle of the eclipse which is just the reverse process.

After giving algorithms for computing eclipses, the *ākṣa*-and *āyana-valanas* are to be computed to know the directions of 1st and last contacts. The formulae are

$$\textit{ākṣā-valana} = \sin^{-1}\left(\frac{\sin Z \times \sin \theta}{\cos \delta}\right)$$

where Z = zenith distance, θ = latitude of the place of observation and δ = declination.

If the planet is in the eastern hemisphere then *ākṣa-valana* is north and if the planet is in the western hemisphere then this is south.

$$\textit{āyana-valana} = \sin^{-1}\left(\frac{\sin \epsilon \times \cos \lambda}{\cos \delta}\right)$$

where λ = longitude of the eclipsed body. If both the *valanas* have same sign, then

sphuṭa-valana = *ākṣa-valana* + *āyana-valana*.
If they have opposite sign, then
sphuṭa-valana = *ākṣa-valana* — *āyana-valana*.

The *sphuṭa-valana* divided by 70 gives the *valana* in *aṅgulas*. The *valanas* are computed for the 1st and last contacts. These give the points where the 1st and

last contacts take place on the periphery of the disc of the eclipsed body with regard to east-west direction of the observer. One can also compute *valanas* for *sammīlana* and *unmīlana* too and decide also their directions.

Solar Eclipse

The *Sūrya-siddhānta* gives the formula for parallax in longitude and latitude. The algorithms of various texts for computing the same are discussed in the next section on parallax. Here we give the rules used in *Sūrya-siddhānta*.

(1) Compute *udayajyā* $= \dfrac{\sin A \times \sin \epsilon}{\cos \theta}$

where A = the *sāyanalagna* = longitude of ascendant at ending moment of amâvâsyâ (computed using *udayāsus* or timings for rising of *rāśis*).

$\cos \theta$ = cosine of latitude = *lambajyā*.

(2) Compute the longitude of *daśamalagna* using *udayāsus*. Calculate the declination δ_D for this longitude.

(3) If δ_D and θ have same direction, subtract the two, otherwise add them. The result is the zenith distance Z_D of the *daśama lagna* (*madhya-lagna* in the terminology of *Sūrya-siddhānta* in chapter on solar eclipse).

$\sin (Z_D)$ is called *madhyajyā*.

(4) Compute *dṛkkṣepa* using the formula

$$dṛkkṣepa = \sqrt{(madhyajyā)^2 - \left(\frac{madhyajyā \times udayajyā}{R}\right)^2}$$

where R is standard radius adopted for tables of sines etc. ($=3438'$ in *Sūrya-siddhānta*)

(5) $dṛggatijyā = \sqrt{R^2 - (dṛkkṣepa)^2} = śaṅku.$

Approximately one can also take $\sin (Z_D)$ to be *dṛkkṣepa* and $\cos (Z_D)$ to be *dṛggati*. *Sūrya-siddhānta* gives this approximation too and defines

$$chheda = \frac{R}{dṛggatijyā}$$

$$viśleṣāṃśa,\ V = tribhona\ lagna - \text{Sun's longitude, (0)}\ \phi\ S_L$$
$$= A - 90 - S_L$$

$$lambana = \frac{\sin (V)}{chheda} \text{ east or west in } ghaṭis.$$

If the Sun is east of the *tribhona-lagna* then the *lambana* is east and if Sun is west of the *tribhona-lagna*, *lambana* is west.

Note that in the approximation here it has been assumed that zenith distances of *madhyalagna* and *tribhona-lagna* are equal (in fact these differ a little). This approximation does introduce some error in *lambana*.

(6) Compute also the *lambana* for the longitude of the Moon.

If $S_L > A - 90°$, the Sun is east of *tribhona-lagna*. In this case subtract the difference of *lambanas* of Sun and Moon from the ending moment of amāvāsyā otherwise add the two. The result is the parallax corrected ending moment of amāvāsyā. Compute the longitudes of Sun and Moon for this moment and recalculate the *lambanas* and again the better *lambana* corrected ending moment of amāvāsyā. Go on correcting recursively till the results do not change.

Now compute the *nati saṃskāra* for correcting the latitude of the Moon using the formula :

$$nati = \frac{(V_m - V_s) \times d\d{r}kk\d{s}epa}{15\,R}$$

$$= 49\; d\d{r}kk\d{s}epa/R = 49\; d\d{r}kk\d{s}epa/3438$$

$$= d\d{r}kk\d{s}epa/70.$$

Apply the *nati* correction to the latitude of the Moon. Using the parallax-corrected ending moment of amāvāsyā and *nati*-corrected latitude of Moon, compute the timing for 1st contact *(sparśa)* 2nd contact (*sammīlana*- time for touch internally, indicating full overlap) 3rd contact (*unmīlana*—start of getting out, indicating touch of the other edge internally) and the eclipsed fraction, *ākṣa-valana, āyana-valana* etc., using the same formulae as given in case of the lunar eclipse. The only difference is that here the eclipsed and eclipsing bodies are Sun and Moon, while these were the Moon and Earth's shadow in case of the lunar eclipse.

In the next chapter *(Parilekhādhikāra) Sūrya-siddhānta* gives the method of depicting the phenomena of contacts etc. diagrammatically using the *mānaikya-khaṇḍa* and *manāntara-khaṇḍa* $(D_1 \pm D_2)/2$ and the *valanas* (to indicate the directions of 1st and last contacts). Such a diagrammatical depiction of eclipses is found almost in every standard text of Hindu traditional astronomy. The details of the method employed are elaborately given by Mahavira Prasada Srivastava.[13]

The illustrative examples for computing lunar and solar eclipses are given by Mahavira Prasada Srivastava[14] and also by Burgess.[15]

It is worthwhile to discuss here how far successfully could *Sūrya-siddhānta* predict solar and lunar eclipses. It may be remarked that the methods as such are quite right but the data used sometimes lead to failure of predictions. The main difference lies in the equations of centre to be applied to the Moon. It may be remarked that the mean longitude of Moon in *Sūrya-siddhānta* is quite correct but the corrections like variation, annual variation, evection etc. (which result from expansion of

gravitational perturbation function for the 3-body problem of Earth-Moon-Sun system in terms of Legendre polynomials of various orders) are lacking. There are thousands of terms for correcting longitude of the most perturbed heavenly body, the Moon. At least nearly fifty or eleven or most unavoidably 4 or 5 corrections are required to be applied to the longitude of Moon and to its velocity, to get satisfactory results. Even if only Muñjāla's correction (evection) is applied, there may result an error of the order of $\frac{1}{2}°$ in longitude of Moon[16] even at syzygies.

It may be remarked here that the *Sūrya-siddhānta* (*S.S.*) applies only one equation of centre (the *mandaphala*) in the longitudes of Sun and Moon. In fact the amplitudes for *mandaphalas* of Sun and Moon were evaluated using two specific eclipses. These were so selected as follows :

(1) One eclipse (solar or lunar) in which the Moon was 90° away from her apogee (or perigee) and Sun on its *mandocca* (lines of apses)

(2) Second eclipse in which the Sun was 90° away from its *mandocca* (or *mandanica*) and Moon was at her apogee.

Although we do not have records of these eclipses for which the data on *mandaphala* were fitted, it is evident that the eclipses might have been so selected that in one case the *mandaphala* of one of them is zero and maximum for the other and vice-versa in the second case. It is clear that the amplitudes of *mandaphalas* in these cases will be the figures used in *Sūrya-siddhānta*. The maximum *mandaphala* (1st equation of centre) for Sun is 2°-10' and for Moon its amplitude is 5°. The actual value in case of Sun being 1°55′ which along with the amplitude of annual variation 15′ amounts to the amplitude (=2°10′) given in *Sūrya-siddhānta*. This evidently indicates that the annual variation got added to the equation of centre of Sun with the sign changed which is also clear if the above-mentioned cases of fitting of data are analysed theoretically. It may be remarked that the *S.S.* equation of centre of Moon does not have annual variation so that at least the *tithi* is not affected by this exchange of the annual variation from Moon to the Sun (as the sign too got changed).

Now it is evident that only those eclipses which conform to the situations given above, (for which the data fitting was done) will be best predicted and the eclipses in which the Sun, Moon are not at their above mentioned nodal points, may not be predicted well or may be worst predicted if they are 45° away from these points on their orbits. The error in longitude of Moon is maximum near *aṣṭami* (the eighth *tithi*)[17] and it is minimum upto 1/2° near syzygies. There had been cases of failure of predictions in the past centuries and attempts were made by Gaṇeśa Daivajña, Keśava and others to rectify and improve the results. The timings may differ or even sometimes in marginal cases, the eclipse may not take place even if so predicted using data of *Sūrya-siddhānta* or sometimes it may take place even if not predicted on the basis of *Sūrya-siddhānta*. The difference in timings (between the one predicted on the basis of *Sūrya-siddhānta* and the observed one) are quite often noted in some cases even by the common masses[18] and for that reason now *pañcāṅga*-makers

are using the most accurate data (although the formulae used in general are the same) for computing eclipses.

The modern methods of computing eclipses use right ascensions and declinations, while Indian traditional methods use longitudes and latitudes and parallax in the ending moments of syzygies (and *nati* in latitude of Moon). The instantaneous velocities are not used. The daily motions even if true, but without interpolations, on being used introduce errors. The locus of shadow cone and the geometry of overlap in the framework of 3-dimensional coordinate geometry is not utilised. The recursive processes do improve the results and the formulae as such are all right but the errors in the true longitudes and latitudes of Sun and Moon and in their velocities lead to appreciable errors.

In fact even Bhāskarācārya in his *Bījopanaya*[19] discussed most important corrections like hybrids of annual variation and variation but missed evection which was earlier found by Muñjāla in his *Laghumānasa*. In 19th A.D. Candrasekhara gave annual variation. If corrections due to Muñjāla, Bhāskarācārya and Candra Shekara are applied simultaneously, results improve remarkably.

In the last century of Vikrama Samvat and also in the last forty years of present century of Vikrama era many Indian astronomers like Ketakara[20] and others advanced the methodology of calculation of eclipses using longitudes and latitudes and prepared *sāranis* (tables) for lunar and solar eclipses (for whole of global sphere). These tables yield very much accurate results.

APPENDIX

If the Sun and Moon have equal declinations with same sign in different *ayanas*, the *yoga* was termed *vyatipāta* and if the signs were opposite but still the magnitudes were equal in same *ayanas* then it was termed as *vaidhṛti* (See fig. 7.1—1(a)(b)). In later developments the *yogas* were given a much more general meaning and these

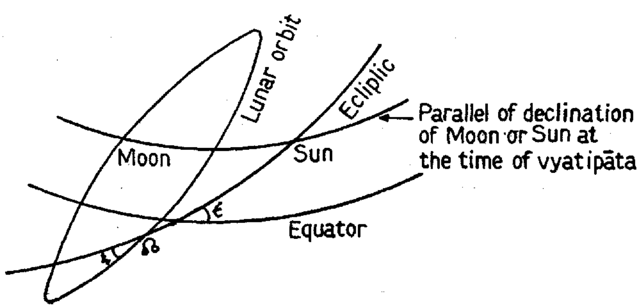


Fig. 7·1 (a)

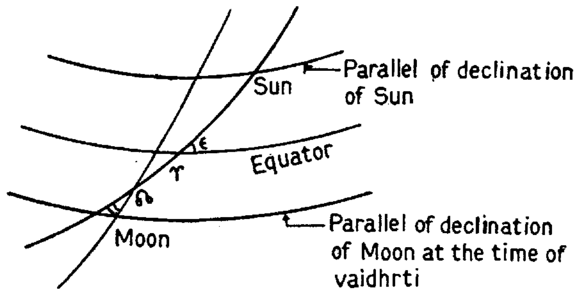


Fig. 7·1 (b)

were defined as sum of longitudes of Sun and Moon. *Yogas* were defined as a continuous function to know the time or day of *vyatipāta* and *Vaidhṛti yogas*. The idea of using this parameter is easily expected because if the latitude of the moon's orbit is neglected then for equality of declinations,

$$\sin S_L = \sin M_L$$

where S_L and M_L stand for longitudes of Sun and Moon respectively which shows, if $S_L = M_L$, $S_L = 180° - M_L$ or $S_L + M_L = 180°$.

Thus the sum of longitudes was treated as a parameter. In order to study the variation of this parameter there were defined 27 *yogas* in siddhāntic texts. This attempt may be visualised as one of the earliest attempts to compute the day (or time) of eclipse or to have an idea of occurrence of eclipse. Jaina texts mention *vyatipāta* and *vaidhṛti yogas*. *Jyotiṣkaraṇḍaka* gives a method of computing only *vyatipāta yogas* in a 5-year yuga. It may be noted that *vaidhṛti* was first defined in *Pauliśa-Siddhānta* (300 B.C.) But the list of 27 *yogas* was computed by Muñjāla (10th century A.D.). The method of computing *krānti sāmya* (timings of equality of declinations) is given in all texts (see "*Jyotirgaṇitam*" *Pātadhikāra*).

PARALLAX (LAMBANA)

Theoretically computed positions of planets (using *ahargaṇa* and equation of centre), are geocentric. Since the observer is in fact on the surface of the Earth, a correction on that account must be applied at the time of observations. The difference between the positions of a planet as seen from the centre and from surface of the earth is called *lambana-saṃskāra* (parallax-correction) or simply the *lambana*. In siddhāntic texts like *Sūrya-siddhānta* etc. it is discussed in the beginning of the chapter on solar eclipse, as this correction depends upon the position of observer and the zenith distance of the planet at the time of observation and thus must be applied in astronomical phenomenon like eclipse. Geometrically we have shown the geocentric position P_1 of the planet P as seen by an observer at the centre of the earth O. The observer

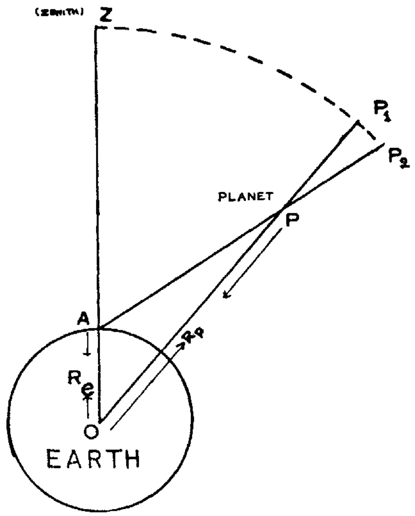


Fig. 7·2

is as the point A on the surface of the earth and his zenith being vertically upward point Z. The position of the planet as seen from A is P. The angle $<APO$ is the *lambana* in the zenith distance of the planet. This is given by

$$\sin p = \frac{R_e}{R_p} \sin z$$

where z = zenith distance
R_e = radius of earth
R_p = OP
= distance of planet
p = $<APO$ = *lambana*.

It may be remarked that the parallax was appearing in the data on lunar observations in early astronomical traditions of pre-siddhāntic period, because the observations were being performed at the time of moonrise and moonset. In these cases maximum value of parallax (horizontal parallax) appeared in their data. In *Purāṇas* and in Jaina literature in Prākṛta[12] there are statements in which it is mentioned that Moon generating its *maṇḍalas* travels higher than the Sun. The statement is usually misinterpreted as mentioning Moon being at larger distance from Earth than the Sun. In fact in such statements the "height" means the latitudinal or declinational height in the daily diurnal motion in *maṇḍalas* (i.e. in spiral-like paths). It is evident that Moon goes upto declinational height of 28°.5 and Sun only upto the declinational height of 23°.5 in Jambūdvīpa. In fact the statements give heights in units of *yojanas* which are just the heights like the ones above sea level. Thus the statements in Purāṇas and Jaina astronomical texts like *Sūrya-prajñapti* mentioning Moon travelling above the Sun, are justified. It is found that[22] 510 yojanas $= 2\,\delta_{max}$

$=47°$ when δ_{max} is the maximum declination (or obliquity) of Sun and the Moon goes higher than Sun by 80 *yojanas* $= \left(\frac{80 \times 47}{51}\right)^{\circ} = 7°.37$. Thus using the data given in Prâkṛta texts of Jainas it is found that latitude of Moon arrived at is $7°.37$. The actual value of latitude of Moon including parallax is $6°.64$ (the actual value without parallax $=5°$). According to the Jaina literature the estimated parallax of the Moon is quite large due to experimental errors. In *Pauliśa-siddhānta* the latitude[23] of the Moon is given to be $4° 30'$, but one verse gives $4°40'$ and there is also a verse [24] giving $7°.83$. This very text gives parallax in longitude in terms of *ghaṭikās* to be added to or subtracted from the time of ending moments of *amāvāsyā* (new moon conjunction). The formula can be written in the following form[25]

parallax = 4 sin (hour angle of Sun) *ghaṭis*. (1)

In *Sūrya-siddhānta* we do not find much details in defining parallax geometrically but the later texts of the siddhāntic tradition have all relevant details. *Sūrya-siddhānta* starts discussing parallax in longitude and latitude stating that parallax in longitude *(harija)* of Sun is zero when it is in the position of *madhya-lagna*[26] (ascendant—90°) and the parallax correction in latitude (*nati* or *avanati*) is zero where the northern declination of the *madhya-lagna* equals the latitude of the place of observation. These facts can be easily visualised applying spherical trigonometrical formulae to solve the relevant spherical triangles. *Sūrya-siddhānta* and other texts in Indian traditional astronomy discuss the parallax corrections in longitude and latitude only.

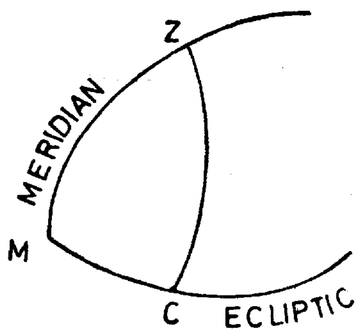


Fig. 7·3

In *Āryabhaṭīya* the parallax is computed as follows:[27]

Let Z be the zenith and M the point of intersection of the ecliptic and ZM the meridian of the place of observation. C is the point of shortest distance of the ecliptic from the zenith (i.e. ZC perpendicular from Z to the ecliptic (Fig. 7.3).
Define

madhyajyā = chord sine of $ZM = \sin(\widehat{ZM})$

udayajyā = chord sine of MZC = sine $(\widehat{MZC})$
where sign on the angular argument indicates that the trigonometric function is evaluated with standard radius (R)

$$\text{Since } \angle ZCM = \pi/2,\ \sin(\widehat{MC}) = \frac{\sin(\widehat{ZM}) \times \sin(\widehat{MZC})}{R}$$

$$= \frac{madhyajy\bar{a} \times udayajy\bar{a}}{R}$$

$$d\d{r}kk\d{s}epajy\bar{a} = \sqrt{(madhyajy\bar{a})^2 - (\sin(\widehat{MC}))^2} \qquad (2)$$

$$d\d{r}ggatijy\bar{a} = \sqrt{\sin^2(\widehat{ZP}) - (d\d{r}kk\d{s}epajy\bar{a})^2}$$

where ZP = zenith distance, $\sin(\widehat{ZP})$ is called *dṛgjyā*.

$$\therefore (d\d{r}ggatijy\bar{a})^2 = (d\d{r}gjy\bar{a}) - (d\d{r}kk\d{s}epajy\bar{a})^2. \qquad (3)$$

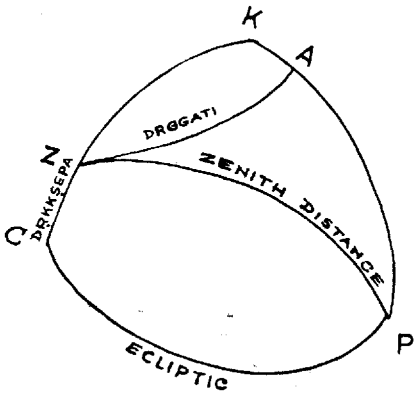


Fig. 7·4

This formula[28] can be proved as follows :
In Fig. 7.4, CP is the ecliptic, P being the planet. K is the pole of ecliptic, Z the zenith of the observer, ZA the perpendicular from Z on the secondary KP. Since ZC $\perp$ CP and $ZA \perp KP$, $\sin^2(\widehat{ZA}) = \sin^2(\widehat{ZP}) - \sin^2(\widehat{ZC})$

$\sin(\widehat{ZC})$ is *dṛkkṣepajyā* and the chord sine of zenith distance ZP is *dṛgjyā*. Chord sine of ZA is *dṛggatijyā*.

$$\text{parallax in longitude} = \frac{R_e \times d\d{r}ggatijy\bar{a}}{R}\ yojanas$$

$$= \frac{R_e \times d\d{r}ggatijy\bar{a}}{\text{planet's true distance in } yojanas}\ \text{minutes}$$

$$\text{parallax in latitude} = \frac{R_e \times d\d{r}kk\d{s}epajy\bar{a}}{R}\ yojanas$$

$$= \frac{R_e \times d\d{r}kk\d{s}epajy\bar{a}}{\text{planet's true distance in } yojanas.}\ \text{minutes}$$

Bhāskarācārya I (629 A.D.)[29] in *Mahābhāskarīyam,* followed Aryabhaṭa's method. Brahmagupta[30] in his treatise *Brāhma-sphuṭa-siddhānta* criticized the approach by Āryabhaṭa. His objection is that *dṛgjyā* is the hypotenuse, *dṛkkṣepajyā* is the base, hence (2) is not valid, but we have shown that this is correct.[28] Brahmagupta's criticism is valid only if the arc between the central ecliptic point and the planet, stands for *dṛggati* as defined by him.

Brahmagupta's method of computing *lambana* is based on evaluating five R sines (chord sines)[31] as follows :

(1) If θ = the latitude of the place,

δc = the declination of the ecliptic point (c) on the meridian.

madhyajyā (as already defined) = R sin (zenith distance of the meridian ecliptic point)

$$= \sin\,(\widehat{ZM}) = \sin\,(\widehat{\theta + \delta c})$$

(2) The R sine of the arc between ecliptic and equator on the horizon is *udayajyā*

$$= \frac{\sin\lambda\sin\epsilon}{\cos\ \theta}$$

where λ = longitude of the point of ecliptic in the east.

ϵ = obliquity of the ecliptic.

(3) *Dṛk-kṣepajyā* is the R-sine of the zenith distance of the central ecliptic point and is given by

$$\textit{dṛk-kṣepajyā} = \sqrt{(\textit{madhyajyā})^2 - \left\{\frac{\textit{udayajyā} \times \textit{madhyajyā}}{R}\right\}^2}$$

(4) *Dṛggatijyā* is the chord sine of altitude of the central ecliptic point.

$$\textit{dṛggatijyā} = \{R^2 - (\textit{dṛk-kṣepajyā})^2\}^{\frac{1}{2}} \qquad (4)$$

Note the difference from eq. (2).

(5) *dṛgjyā* = sin $(\widehat{\textit{zenith distance}})$ = sin $(\widehat{z})$. It is given by

$$\textit{dṛgjyā} = \left(R^2 - \left\{\frac{\textit{dṛggatijyā} \times \sin\,(\lambda - S_L)}{R}\right\}^2\right)^{\frac{1}{2}}$$

where S_L = longitude of the Sun

$$\textit{lambana} = \frac{\textit{dṛgjyā} \times \text{Earth's semidiameter}}{\text{distance of the planet in } \textit{yojanas}} \text{ (in minutes of arc).}$$

In eclipse-calculations the difference between *lambanas* of Sun and Moon is required. So sometimes this difference is called *lambana* (the parallax for computation of eclipses).

$$\textit{lambana } P' = \left\{\frac{(\textit{dṛgjyā} \text{ of Moon})^2 - (\textit{dṛk-kṣepajyā} \text{ of Moon})^2}{\text{Moon's true distance}}\right\}^{\frac{1}{2}} \times 18$$

$$= \left\{\frac{(\textit{dṛgjyā} \text{ of Sun})^2 - (\textit{dṛk-ksepajyā})^2}{\text{Sun's true distance}}\right\}^{\frac{1}{2}} \times 18 \text{ in minutes of arc}^{32}$$

where the factor 18 is obtained from the value of the Earth's semidiameter.

This can be converted into *ghaṭis* using ratio proportion with difference between daily motions of the Sun and the Moon.

$$p \text{ (in } ghaṭis) = \frac{60}{d} \times P'$$

where d is the difference between daily motions of Moon and Sun in minutes of arc.

For solar eclipse, parallaxes in longitudes of Sun and Moon and the parallax correction in latitude of the Moon *(nati)* are required.

The *nati* is given by

$$nati = \frac{(dṛk\text{-}ksepajyā \text{ of Moon}) \times 18}{\text{Moon's true distance}} - \frac{(dṛk\text{-}ksepajyā \text{ of Sun}) \times 18}{\text{Sun's true distance}} \text{ in minutes of arc.}$$

Moon's true latitude $=$ Moon's latitude $\pm$*nati*.

Sūrya-siddhānta and Brahmagupta both compute the *lambana* and *nati* using the formulae:

$$lambana = \frac{\sin(M - S_L) \times dṛggatijyā}{(\sin 30^\circ)^2} \quad ghaṭis$$

M = longitude of the meridian ecliptic point.

$$nati = \frac{dṛk\text{-}kṣepajyā\ (V_m - V_s)}{15\,R} \quad \text{(in units of those of velocities)}$$

where V_m and V_s stand for the daily motions of the Sun and the Moon.

Bhāskarācārya gave simpler algorithm for computing horizontal parallaxes of planets. According to this algorithm the daily velocity of planet divided by 15 gives the parallax.[33] This formula is quite evident because the parallax of any planet is the radius of the Earth in the planet's orbit. The radius of the Earth = 800 *yojanas* and daily velocity of each planet according to *Sūrya-siddhānta* is equal to 11858.72 *yojanas*. We know that the ratio of the daily orbital motions = ratio of the orbit's radii. Hence

$$\text{Parallax } p = \frac{\text{velocity of planet}}{15} \quad \text{(in units of those of velocity).}$$

Since day = 60 *ghaṭis*, hence horizontal parallax is almost the angular distance travelled by planet in 4 *ghaṭis*. It may be remarked that in fact the distances (in *yojanas*), daily travelled by planets are not the same, hence the results were inaccurate. The following table shows the figures for comparison.[9]

Table 7.1. *Table showing Bhāskara* II's *horizontal parallax for each planet and modern values.*

Planets	Bhāskarācārya's horizontal parallax	Modern observations yield horizontal parallax Minimum	Maximum
Sun	236″.5	8″.7	9″.0
Moon	3162″.3	3186″	3720″
Mars	125″.7	3″.5	16″.9
Mercury	982″.1	6″.4	14″.4
Jupiter	20″.0	1″.4	2″.1
Venus	384″.5	5″.0	31″.4
Saturn	8″.0	0″.8	1″.0

Note that only the parallax of the Moon is fairly correct. This resulted in reasonable success in predictions of eclipses.

In later traditions for the computation of eclipses, *Makaranda-Sāraṇi*[34] is famous. This has the following algorithms for computing *lambana* and *nati*

(1) At the time of ending moment of *amāvāsyā* compute Sun's declination $= \delta_S$ and declination of *tribhona-lagna* (A = ascendant—90°) $= \delta_A$.

(2) Zenith distance of $A = Z_A = \delta_A \pm \theta$, (+ve if θ and δ_A are oppositely directed,—ve sign if these have same sign).

(3) If $\left(\frac{Z_A}{22}\right)^2 > 2$ subtract 2 from this.

(4) Compute $hara = \left\{\left(\frac{Z_A}{22}\right)^2 + \left[\left(\frac{Z_A}{22}\right)^2 - 2\right]\right\}^\circ + 19^\circ$.

(5) $lambana = \left[14 - \left(\frac{S_L - A}{10}\right)\right] \times \left(\frac{S_L - A}{10}\right)$ *ghaṭikas* to be applied in ending moment of amāvāsyā.

If *tribhona-lagna* $A > S_L$ then it is to be added to and if $A < S_L$ then it is to be subtracted from ending moment of amāvāsyā.

(6) $13 \times$ *lambana* = *lambana* in minutes of arc = (in minutes of arc)

(7) Compute $S_L - \Omega \pm l = a =$ *lambana* corrected latitude argument (*śarakendra*).

where Ω = longitude of Rāhu.

Using a as argument (*śara-kendra*) compute latitude of Moon, as per algorithm. given in the text (*Makaranda-sāraṇi*). Let it be denoted by P_m.

(8) $A \pm 6 \times P_m$ = *lambana-corrected tribhona-lagna* $= A'$ (say).
A'+angle of precession a *sāyanatribhona-lagna* $= A''$ (say).

(9) Compute the declination corresponding to the longitude A''. Let it be $\delta_{A''}$.

(10) $\theta \pm \delta_{A'}$ = zenith distance of *lambana*-corrected *tribhona-lagna* = $Z_{A'}$ (say).
(11) Compute $(18-Z_{A'}/10)\ Z_{A'}/10$ in minutes of arc y (say).
(12) Compute $378-y$ = Remainder (in minutes of arc) = r (say).
(13) *nati* $= y/r$.
It has same sign as that of $Z_{A'}$.
(14) Moon's latitude $\pm$ *nati* = true latitude of Moon.

Later Kamalākara Bhaṭṭa who compiled his *Siddhānta-tattva-viveka*[35] in 1656 A.D. made an exhaustive analysis of the *lambana* and *nati* corrections. This is by far the most detailed analysis. He criticised Bhāskarācārya's approach as well as the treatment done by Munīśvara in *Siddhānta-sārvabhauma* and pointed out the approximations, used by them in their derivations. It may be remarked that Kamalākara's treatment is probably the most exhaustive of all the treatments available in astronomical literature in Sanskrit. He has categorised *lambana* corrections in various elements and gave sophisticated spherical trigonometric treatment in order to study the values in different geometrical positions for applications in solar eclipse computations.

It may be noted that in Indian astronomy, *lambana* is applied in observations of Moon, moonrise and moonset and in computing solar eclipses etc. but it was never applied in *tithis*, which have same ending moment all over the global sphere.[36] It was not applied in computing cusps of Moon but the same should have been applied.[37]

It may be pointed out that the advancements in developing formulae for computing *lambana* and *nati* by Indian astronomers upto Kamalākara Bhaṭṭa (before Newton) are very much appreciable, but these corrections were done in longitude and latitude only, in terms of parallax in zenith distance and no formulae for parallax corrections in right ascension and declination were developed because eclipses were calculated using ecliptic coordinates only and never the equatorial coordinates.

PRECESSION

From Vedic and Post-Vedic literature, it can be easily inferred that the phenomenon of precession was qualitatively known to Indian astronomers of those times although its velocity was not known. We find the lists of lunar asterisms *(nakṣatras)*, starting with Śraviṣṭhā (Dhaniṣṭhā—an asterism of lunar zodiac identifiable with the star alpha or beta delphini) at the time of *Vedāṅga-Jyotiṣa*[38] and the list found in Jaina literature[39] has asterism Abhijit (identified as Vega star α-Lyrae) as the 1st asterism (the positions of nodal points of ecliptic at the time of *Sūrya-prajñapti* are shown in the figure 8.1), which clearly indicates that the starting *nakṣatra* was changed from time to time, whenever an appreciable change got accumulated in the position of winter solstice among the stars. According to B. G. Tilak[40] there were also times when spring equinox was in the constellation Mṛgaśīrṣa (the "Orion") which corresponds to the position of winter solstice in the asterism Uttarābhādrapadā, 3 *nakṣatras* (about 40°) ahead of Dhaniṣṭhā *nakṣatra*. In fact there were two types of traditions developed in vedic and post-vedic period.[41] According to one tradition

winter solstice marked the beginning of year and according to the second tradition the beginning of the year was with Sun's passage at spring equinox. At the time of the *Śatapatha Brāhmaṇa* the spring equinox was near the constellation Kṛttikās (pleiades).[42]

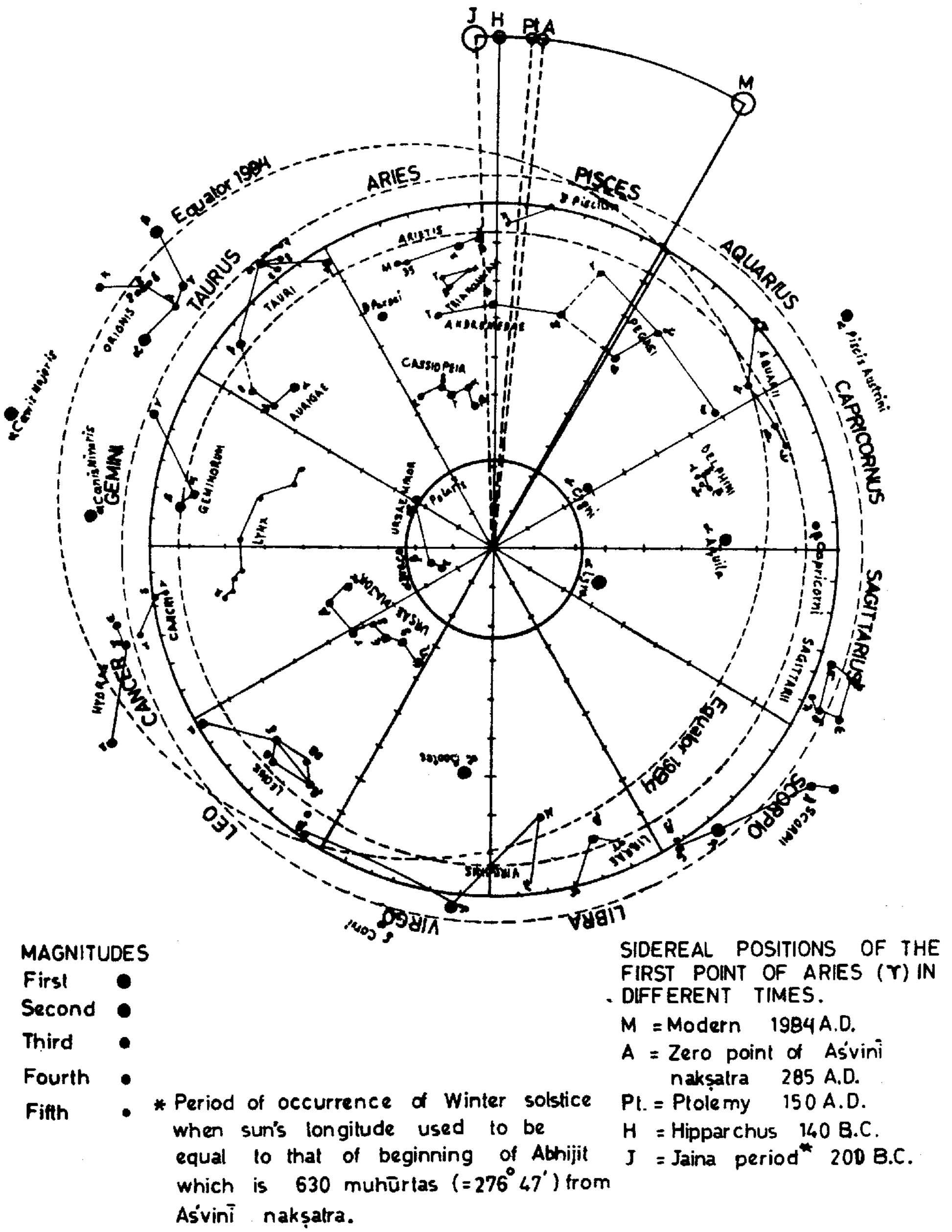


Fig. 7·5
The Zodiac through ages.

Later this shifted to Bharaṇī asterism at the time of *Sūrya-prajñapti* and to the asterism Aśvinī (identified with the star alpha or beta Arieties) in the Siddhāntic period. These days the list of *nakṣatras* starts with Aśvinī. No change was done by the astronomers of the siddhāntic period. This is due to the reason that the *nirayaṇa* (sidereal i.e. without precession) zodiac got accepted in the tradition, although the Hindu year was tropical. (This fact will be discussed later). All the later treatises are using *nirayaṇa* longitudes and their respective *ayanāṃśas* as the difference between the analytically computed and observed position of the Sun. It may be noted that from early Vedic time upto the time of Brahmagupta including *Vedāṅga Jyotiṣa, Sūrya-prajñapti, Pañca-siddhāntikā, Āryabhaṭīya, Brāhmasphuṭa-siddhānta* etc., only the *sāyana* (Tropical) longitudes were used. In earlier literature we clearly find change in the order of *nakṣatras* in the zodiac list after an accumulation of precession equal to 1 *nakṣatra* (=13°20′) or more, but now the precession with respect to beginning of Aśvinī is about 23°38′ but 1st *nakṣatra* of the list has not been changed by any astronomer over about 2000 years. Here in figure 7.5 we have shown the position of spring or vernal equinox among the stars. Here the Jaina period has been fixed around 200 B.C. taking into consideration the list of nakṣatras in *Sūrya-prajñapti.*[43] For comparison the position of the vernal equinox at the time of Hipparchus (140 B.C.) too is shown in the diagram. As pointed out earlier in Aryan traditions, the beginning of the year was taken with Sun's position at spring equinox or winter solstice, but after the time of *Sūrya-prajñapti* the vernal equinox position of Aśvinī was almost exclusively taken as beginning of year and the winter solstice position got almost dispensed with in reckoning the beginning of the year.

Although Hipparchus (2nd century B.C.)[44] is accredited with the discovery and categoric statement of the shift due to precession in the positions of stars with respect to spring equinox from the time of Timocharis of Alexandria (280 B.C.) yet there is no doubt that even Vedic Hindus shifted the zero of their zodiac from time to time and thus, were knowing the phenomenon of precession. Ptolemy (150 A.D.) gave the velocity of precession to be about 36″ per annum which was improved by later astronomers. In the Indian tradition, although the 1st nakṣatra in the lists was changed from time to time, with the changes in the position of spring equinox, the actual magnitude and rate of precession in the Hindu tradition is not found before siddhāntic period. After the advent of siddhāntic (theoretical) astronomy, Viṣṇucandra in *Vasiṣṭha Siddhānta* mentions the *yuga* of *ayana* (precession)[45 46] which gives the rate of precession as 57″ P.A.[45 47] The phenomenon is referred to in *Romaka Siddhānta* also[46] and it is argued that the shift of solstices among stars is not possible without precession of equinoxes. These authors were criticised by Brahmagupta,[48] Bhaskara I[49] (600 A.D.) etc. Varāhamihira mentioned the *ayana calana* hypothesis[50] and suggested verifications through actual observations.[51] In fact because of small angle of precession or due to no belief in *ayana-calana*-hypothesis, the precession was ignored by Āryabhaṭa, Bhāskara I and Brahmagupta etc. It was Muñjāla (10th century A.D.) who started using *ayanāṃśa* which had accumulated to about 6° by that time. Probably at that time, there was confusion in *saṃkrāntis* (Solar ingresses or transits from one sidereal sign to the next) and he had to remove the confusion by fixing the value of *ayanāṃśa* through experimental observations. Viṣṇucandra and

Muñjāla believed in uniform regression of equinoctial point up to complete cycle, while present *Sūrya-siddhānta* uses the hypothesis of oscillatory motion (trepidation) of equinoxes. (This hypothesis will be discussed in details in the next section). The rate of precession according to Viṣṇucandra is about 56″.9 P.A. (number of cycles in a *kalpa*=189411). According to Muñjāla the rate is 59″.2 P.A. (number of cycles in a *kalpa*=199669). These are uniform regressional motions. According to *Sūrya-siddhānta* the cycle of oscillatory motion has a period of 7200 years, but it is strange that rate of precession is again uniform 54″ P.A. and it is not oscillatory which is against laws of oscillatory motion.

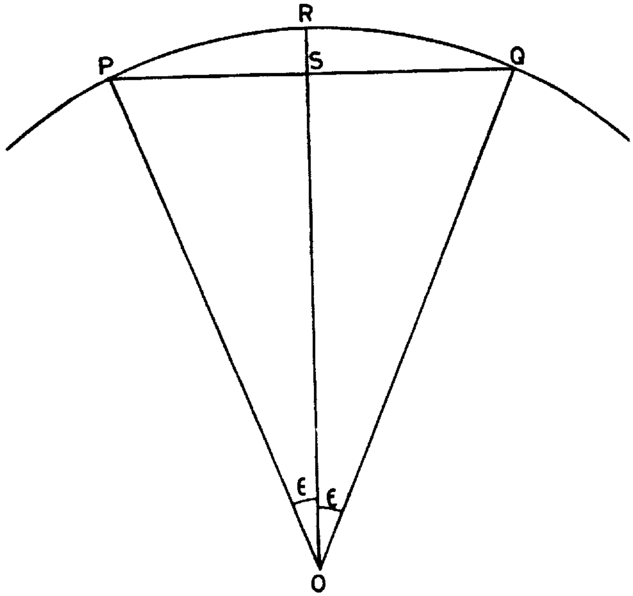


Fig. 7.6

The technique used for horizontal observation in *Sūrya-prajñapti* and *Śulba-Sūtras*.

THE LENGTH OF SOLAR YEAR, SIDEREAL OR TROPICAL

In *Vedāṅga-jyotiṣa* the length of solar year was taken to be 366 days and this was used in Vedāṅga calendar of 5-year *yuga* having two intercalations in 5 years. Later in *Sūrya-siddhānta* we find the solar year to be equal to 365 days 15 *ghaṭis* 31 *palas* and 30 *vipalas* (365^d—6^h—12^m—24^s). In fact, methods for determining solar year are given in *Sūrya-prajñapti* (and *Śulba-sūtras*). At that time there was not known any distinction between tropical and sidereal years. The Sun was observed while rising and setting every-day, throughout the year. The length of the year was computed by counting the number of days and a fraction thereof on the last day at any of the cardinal points preferably solstices, as the Sun appears to be stationary there. In diagram 7.6 is given the experimental technique described in *Sūrya-prajñapti*.

At winter solstice Q one starts observing the Sun while rising in the east with the help of a stick or a *nalikā* (tube).[52] A *davarikā* (thread) PQ was also used in these

experiments. The arc *PRQ* is graduated in 124 divisions and 124 subdivisions in the fashion of Vedāṅga astronomical tradition (the figure 124 being the total number of syzygies in 5 year *yuga*). P is the summer solstice position of the Sun. At this point the fraction of the day is computed using ratio proportion and it was estimated that on the last day it went up to 144 ($=124+20$) subdivisions (i.e. 20 subdivisions in excess) and same situation occurred on the winter solstice day on Sun's back return journey. This way the length of the year can be shown to be $365+\frac{2\times 20}{124}=365\frac{1}{3}$ days.[53]

Generally it is believed that Indian astronomers did not determine the length of solar year experimentally and adopted the value as given in *Sūrya-siddhānta* from external sources but this decoding of experiment on determination of solar year in *Sūryaprajñapti* disproves this hypothesis. Such experiments were being performed in early vedic times too. The earliest report on such observations is found in *Aitrareya Brāhmaṇa.*[54] The position of Sun at any point on the horizon of any locality is specified by its declination, so it is evident that this method will yield tropical year and not the sidereal year. Thus it is clear that by the word "year" the Hindu astronomers of pre-siddhāntic period meant tropical *(sāyana)* year. In fact they were not aware of sidereal *(nirayaṇa)* year. This very traditional way of determining solar year is found in the *Siddhānta śiromaṇi* of Bhāskarācārya and other Siddhāntic texts but we do not find any method of determining really sidereal year in any Siddhāntic text of Indian Astronomy. In fact almost the same was the situation in other traditions of olden times. It was Piccard who actually determined the sidereal year length by taking record of right ascensions of Sun at specific times with an interval of 76 sidereal years (A.D. 1699-1745).[55]

From what has been discussed, it is evident that the Hindus in fact never intentionally used sidereal year. In all experimental methods (described in Siddhāntic texts) one gets only the tropical year and never sidereal year. This way one can infer that it was error in the determination of solar year (of the order of 24 minutes in excess to the actual tropical year)[56] which was responsible for creating confusion of taking tropical year for the sidereal year. There is no doubt that this value got into use in Hindu traditions and now no almanac maker is ready to accept tropical year for religious Hindu calendar. It is also possible that they intended to use year in sidereal sense but it happened to be tropical year within the available means they adopted to measure the "year" in general sense.

Hypothesis of Trepidation of Equinoxes

Inspite of the fact that the year length in Indian tradition was intended to be tropical, the sidereal year got enforced into use unintentionally. The later astronomers started believing in the hypothesis of trepidation of equinoxes, according to which the spring equinox oscillates (trepidates) upto $\pm 27°$ on both sides of the fixed zero of zodiac. It takes about 27000 years to complete this cycle. This way the zero of the zodiac was thought to get restored twice in each cycle and thus the same was not changed instead the return was awaited, after it reached 27° from the Aśvinī *nakṣatra.*

It may be pointed out that Āryabhaṭa II and Parāśara believed in $\pm 24°$ amplitude of trepidation.[57] The rate of precession adopted by Āryabhaṭa II was 46″.5 P.A.[58] It may be remarked that neither Muñjāla nor Bhāskarācārya nor others in Hindu astronomical tradition, have categorically mentioned the oscillation of equinoxes. Only in the present recension of *Sūrya-siddhānta,* we find a statement[59] which gives the method of computing *ayanāṃśa* using throughout a constant velocity of 54″ P.A. In this method, 27° get subtracted adhoc whenever it goes in excess to this amplitude. This has no mathematical or physical validity (as, unless velocity is gradually reduced to zero, its direction cannot change).[60] Moreover, even in *Sūrya-siddhānta,* the relevant *ślokas* evidently appear to be added later on; as these use a different style of enumerating figures by actual numbers and not as usual (in all other parts) by symbols like *netra* (eyes) = 2, *candra* (Moon) = 1, etc. Also in the body of the text, there is no use of *ayanāṃśa* as such in computing *lagna* (ascendant) etc. There is just a general statement asking the use of *ayanāṃsa* for computing gnomonic shadows, ascensional differences etc., in that very *śloka,* where the formula for computing the same has been given.[61]

Even ancient records show that *ayanāṃśa* was greater than 27°. For example, at the time of *Śatapatha Brāhmaṇa* when Kṛttikās are said to rise in the east.[62] the *ayanāṃśa* comes out to be 45°. Thus it is not worthwhile to wait for *ayanāṃśa* to accumulate to a value greater than 27° in future, and keep on believing the hypothesis of trepidation of equinoxes. The law of gravitation has discarded this hypothesis and explained the phenomenon of full cycle of precession on the basis of the torque exerted by Sun and Moon on the spheroidal earth.

Brenand[63] and Vijñanānanda Swāmī[64] tried to explain the oscillatory motion of the *ayana* by taking projections of ecliptic, solstitial colure etc., in one plane, but such an argument may hold for any value of maximum amplitude of the angle of precession.[65] In our opinion the oscillations described in *Sūrya-siddhānta* may not mean more than the declinational north south oscillations of stars on the eastern horizon due to precession of equinoxes over the period of 27000 years. Thus the hypothesis of trepidation of equinoxes has no physical validity. On the other hand, the theory of precession of equinoxes and its full cycle, is the final verdict of the law of gravitation.

The Zero of Hindu Zodiac and Various Schools of Ayanamśa

As we have pointed out earlier, the zero of the zodiac got fixed at Aśvinī after *Sūryaprajñapti* (200 B.C.) when theoretical astronomy started. The various treatises took their own computed position of the Sun to be exact and defined the *ayanāṃśa* as the difference between its observed and computed positions. Thus the velocity of *ayana* was erroneous. The sidereal solar year adopted in *Sūrya-siddhānta* is in excess to the actual value (determined by Piccard by taking observations over a range of 76 years)[66] by about $8\frac{1}{2}$ *palas* (= 3.6 minutes). Due to this error the analytically computed celestial sidereal longitude of the Sun will be erroneous and as a consequence, the sidereal zero of the zodiac is invariably expected to be changed if one adopts the siddhāntic definition of *ayanāṃśa* and its velocity. The velocity of

precession according to *Sūrya-siddhānta* is 54″ per annum while according to *Graha-lāghava* it is 60″ per annum and other texts have somewhat different velocities. These velocities include also the errors due to inaccuracies in the measurement of solar year. As already pointed out, the solar year as determined by the methods described above, is tropical *(sāyana)*. In fact there is a difference of about 20 minutes between the *sāyana* and *nirayaṇa* years, (*nirayaṇa* year being in excess). The methods adopted for determining the length of year were erroneous to the extent that error of the order of 20 minutes masked the difference between the two solar years and in fact, because of no notion of the difference between the two, the tropical year so determined, with that much error, got adopted as sidereal year and it happened to be in excess (by about 3.6 minutes) to the actual sidereal year length. As a result of adopting this year length and Sun's longitude as eaxct, zero of the zodiac went on shifting from the actual position and about 3½ degrees got accumulated in about 2000 years (since the time of switch over from *Vedāṅga* traditional calendar of 5 year *yugas*, to the siddhāntic tradition of calendar making). In the last decades of 19th century A.D. traditional *pāñcāṅga*-makers were trying to fix the zero of Hindu zodiac by adopting the modern value for precessional velocity or by back calculating the position of spring equinox in conformity with the data of *Sūrya-siddhānta* or other standard treatises of Indian tradition. Since the polar longitudes of stars etc. given in *Sūrya-siddhānta* can not yield a consistent *ayanāṃśa*, the problem of *ayanāṃśa* remained a vexed question. There were many rival publications by Govinda Sada Siva Apte and Dina Natha Shastri Chulet and many others.[67] These conflicts gave rise to two different prominent schools *Raivata pakṣa* and *Citrā pakṣa* among the followers of the modern school (called the *Dṛk-pakṣa*, the school believing in observations). The third one being the *Surya-siddhānta* school which has erroneous rate of precession. According to the *Raivata pakṣa* the *ayanāṃśa* is about 3½ degrees less than the value in the *Citrā* school. If the zero of zodiac is defined as the position of spring equinox at the time of switch over from the Vedāṅga to siddhāntic tradition of *pañcāṅga*-making, the *Raivata pakṣa* has sound justification, because if year length had 8½ *palas* error, the same must have been accumulated. According to the exponents of *Citrā* school the zero is 180° away from 1st magnitude star Spica or α-Virginis *(Citr)*. In fact the authors of various treatises over the past 1500 years too, did try to fix the zero of Hindu zodiac from time to time. Zeros of the zodiac are different in various treatises as tabulated below.[69]

Siddhānta-text	Year of zero *ayanāṃśa*
Present *Sūrya-siddhānta, Vasiṣṭha-siddhānta* etc.	421 *Śaka*
Muñjāla's *Laghumānasa*	449 ,,
Rājamṛgāṅka Karaṇaprakāśa, Karaṇa Kutūhala*	445 ,,
Grahalāghava	444 ,,
Bhāsvati-karaṇa	450 ,,
Second *Āryabhaṭa Siddhānta*	527 ,,
Bhaṭatulya (by Damodara)	342 ,,

*It is interesting to note that one of the manuscripts of *Rājamṛgāṅka* has no *ayanāṃśa* formula. It is guessed that *ayanāṃśa* was added after *graha-lāghava*, which indicates that *ayanāṃśa* took long time to get into common use.[69]

It is clear that there were attempts to fix the zero of the zodiac to dates before Āryabhaṭa.

Note that changes in zero of zodiac were done upto the time of *Grahalāghava* (16th century A.D.). Thus there were quite different years of zero *ayanāṃśa* as shown in the table above. Indian Calendar Reform Committee[70] under the Chairmanship of late Prof. M. N. Saha, analyzed the problem using polar longitudes of stars given in the *Sūrya-siddhānta* and concluded that the zero was being fixed again and again by different Jyotiṣācāryas in their own times. There exists difference upto over 3° or so in different treatises of astronomy, but certainly the zero of Hindu zodiac is about 2° removed from that of Ptolemy's. From this analysis it is clear that it is not the zero of the Vedāṅga zodiac which we have in modern *Sūrya-siddhānta*. Thus not going by any old text, the followers of *Citrā pakṣa* fixed the zero at that very point to which the equinox had shifted upto 1800 śaka or so (as used by V. B. Ketakara)[71] and adopted the accurate value of precessional velocity so that no more error is accumulated in future years. A fact has to be stated that previously V. B. Ketakara too published *Jyotirgaṇitam* using *Raivata pakṣiya ayanaṃśa*, but on the advice of Sankara Bala Krishna Dixit, he destroyed all copies of the same and rewrote and published the *Citrā pakṣiya Jyotirgaṇitam*. He even deleted a *śloka*[72] (on the advice of S. B. Dixit) in which he had clarified that it was the *Raivata Pakṣa* which was justified but because of its unacceptability in the social practices he started *Citrā Pakṣa* which would go parallel to *Sūrya-siddhānta* for a century or so and thus get adopted by that time. The Calendar Reform Committee has advised to fix the *ayanāṃsa* at 23°15′ (a value for Jan. 0,1955 A.D.) and started taking most accurate expressions for precessional velocity and also the nutation. The Committee proposed a *Sāyana Śaka* year beginning with 21st March (22nd March in case of leap year) but it could not be accepted by traditional *pañcāṅga* makers. The zero of zodiac in this system is moving with same velocity as that of precession but it will always be at a constant distance of 23°15′ from the position of spring equinox. For defining lunar months it will be a good plan if the constant precession 23°15′ is used without further change with the precessional velocity.[73] This way the lunar months will be defined with respect to *sāyana* longitude of the Sun minus 23°15′ at the ending moment of respective *amāvāsyās*. This way, the change in the limits of lunar months with respect to tropical calendar (say Gregorian Calendar) accumulated up to 1955 A.D., will not increase any more in years to come. Consequently the lunar months will get pegged on to *sāyana* solar year and this change may not be noted by ordinary people to result in disorders in social practices. This way the luni-solar religious calendar will conform to seasons at least to the extent it was in 1955 A.D. But this technique cannot be accepted unless it gets the sanction of Hindu religious authorities. Since the names of lunar months are conforming to the asterisms occupied by the Moon at the ending moments of full-moon syzygies and many festivals are related with asterisms, the *pañcāṅga* makers find it difficult to adopt the constant precession system for deciding religious rites. This is the reason why the proposals of the Calendar Reform Committee did not receive recognition and in near future there is no hope to switch over to *sāyana* system or constant precession system of calendar-making for Hindu religious rites.

8

PHASES OF THE MOON, RISING AND SETTING OF PLANETS AND STARS AND THEIR CONJUNCTIONS

K. S. SHUKLA

INTRODUCTION

It has been known from time immemorial that the Moon is intrinsically a dark body but looks bright as it is lighted by the Sun. There is an oft-quoted statement in the *Yajurveda*[1] which describes the Moon as sunlight. As the Moon revolves round the Earth its lighted portion that faces us is seen by us in successively increasing or diminishing amounts. These are called the phases of the Moon.

When the Sun and Moon are in the same direction, the face of the Moon which is turned towards us is completely dark. It is called new-moon and marks the beginning of the light fortnight. When the Moon is 12 degrees ahead of the Sun, it is seen after sun-set in the shape of a thin crescent. As the Moon advances further this crescent becomes thicker and thicker night after night. When the Moon is 180 degrees away from the Sun, the Moon is seen fully bright. It is called full-moon. The light fortnight now ends and the dark fortnight begins. The phases are now repeated in reverse order until the Moon is completely dark at the end of the dark fortnight when the Sun and Moon are again in the same direction.

Vaṭeśvara says :

"The Sun's rays reflected by the Moon destroy the thick darkness of the night just as the Sun's rays reflected by a clean mirror destroy the darkness inside a house.[2]

"In the dark and light fortnights the dark and bright portions of the Moon (gradually) increase as the Moon respectively approaches and recedes from the Sun."[3]

"On the new-moon day the Moon is dark; in the middle of the light fortnight, it is seen moving in the sky half-bright; on the full moon day it is completely bright as if parodying the face of a beautiful woman."[4]

"The crescent of the Moon appears to the eye like the creeper of Cupid's bow, bearing the beauty of the tip of the Ketaka flower glorified by the association of the black bees, and giving the false impression of the beauty of the eyebrows of a fair-coloured lady with excellent eyebrows."[5]

"When the measure of the Moon's illuminated part happens to be equal to the Moon's semi-diameter, the Moon looks like the forehead of a lady belonging to the Lāṭa country (Southern Gujarat)."[6]

Similar statements appear in the writings of Varāhamihira and other Indian astronomers.

Phase and Sita

In modern astronomy the phase of the Moon is measured by the ratio of the central width of the illuminated part to the diameter. In Indian astronomy it is generally measured by the width of the illuminated part itself which is called *sita* or *śukla*. The width of the unilluminated part, which is equal to 'the Moon's diameter *minus* the *Sita*', is called *Asita*.

The *Pūrva-khaṇḍakhādyaka* of Brahmagupta, which summarizes the contents of Āryabhaṭa I's astronomy based on midnight day-reckoning, gives the following approximate rule to find the *sita* in the light half of the month:

"The difference in degrees between the longitudes of the Sun and Moon, divided by 15, gives the *śukla* (in terms of *aṅgulas*)."[7]

Stated mathematically, it is equivalent to the following formula:

$$sita = \frac{M - S}{15} \text{ } a\dot{n}gulas.,$$

where S and M denote the longitudes of the Sun and Moon respectively, in terms of degrees. This formula may be obtained by substituting

$$\text{Moon's diameter} = 12 \text{ } a\dot{n}gulas$$

in the general formula :

$$sita = \frac{(M - S) \times \text{Moon's diameter}}{180}. \tag{1}$$

Bhāskara I (629), a follower of Āryabhaṭa I, who claims to have set out in his works the teachings of Āryabhaṭa I, however, gives the following rule:

"(In the light fortnight) multiply (the diameter of) the Moon's disc by the R versed-sine of the difference between the longitudes of the Moon and the Sun (when less than 90°) and divide (the product) by the number 6876: the result is always taken by the astronomers to be the measure of the *sita*. When the difference between (the longitudes of) the Moon and the Sun exceeds a quadrant (i.e. 90°), the *sita* is calculated from the R sine of that excess, increased by the radius.

"After full moon (i.e. in the dark fortnight), the *asita* is determined from the R versed-sine of (the excess over six or nine signs, respectively, of) the difference

between the longitudes of the Moon and the Sun in the same way as the *sita* is determined (in the light fortnight)."[8]

That is to say :

(i) In the light fortnight *(śukla-pakṣa)*

$$sita = \frac{R \text{ versin } (M\text{—}S) \times \text{Moon's diameter}}{6876},$$

if M—$S \leqslant 3$ signs, i.e. if it is the first half of the fortnight; and

$$= \frac{[\,R + R \sin\ (M\text{—}S\text{—}90°)\,] \times \text{Moon's diameter}}{6876},$$

if M—$S > 3$ signs, i.e. if it is the second half of the fortnight.

(ii) In the dark fortnight *(kṛṣṇa-pakṣa)*

$$asita = \frac{R \text{ versin } (M\text{—}S\text{—}180°) \times \text{Moon's diameter}}{6876},$$

if M—$S > 6$ signs, i.e. if it is the first half of the fortnight; and

$$= \frac{[\,(R+R \sin\ (M\text{—}S\text{—}270°)\,] \times \text{Moon's diameter}}{6876},$$

if M—$S > 9$ signs, i.e. if it is the second half of the fortnight.

Bhāskara I's contemporary Brahmagupta (628) gives the following rule, which is a via media between the above two rules:

"One half of the Moon's longitude minus Sun's longitude, multiplied by the Moon's diameter and divided by 90, gives the *sita*. This is the first result.

"When the Moon's longitude minus Sun's longitude, reduced to degrees, is less than or equal to 90°, take the R versed-sine of that; and when that exceeds 90°, take the R sine of the excess over 90° and add that to the radius. Multiply that by the measure of the Moon's diameter and divide by twice the radius (i.e. by 2×3438 or 6876). This is another result. The former result gives the *sita* in the night and the latter in the day. One half of their sum gives the same during the two twilights."[9]

That is :

$$\text{(i) } sita \text{ for night} = \frac{[\,(M\text{—}S)/2\,] \times \text{Moon's diameter}}{90},$$

M—S being in degrees.

$$\text{(ii) } sita \text{ for day} = \frac{R \text{ versin } (M\text{—}S) \times \text{Moon's diameter}}{2R},$$

if M—$S \leqslant 90°$; or

$$= \frac{[\,R+R \sin\ (M\text{—}S\text{—}90°)\,] \times \text{Moon's diameter}}{2R},$$

if $M - S > 90°$. ($R = 3438$)

(iii) *sita* for twilights $= \dfrac{\textit{sita} \text{ for day} + \textit{sita} \text{ for night}}{2}$.

These formulae obivously relate to the light half of the month.

Vaṭeśvara[10] (904) and Śrīpati[11] (1039) have followed Brahmagupta. Lalla[12] gives the two results stated by Brahmagupta, treating them as alternative. But whereas his commentator Mallikārjuna Sūri (1178) interprets them as alternative rules, his other commentator Bhāskara II (1150) makes no distinction between the rules of Brahmagupta and Lalla and interprets them in the light of Brahmagupta's rules. Bhāskara II has also attempted to explain why different formulae were prescribed for day, night and twilights. He says: "The first *sita,* being based on arc, is gross. This is to be used in the graphical representation of the Moon in the night, because then there is absence of the accompaniment of the Sun's rays. The second *sita*, being based on *R* sine, is accurate. This is to be used in the graphical representation of the Moon in the day, because then the Moon's rays being overpowered by the Sun's rays are not bright. During the twilights, the *sita* should be obtained by taking their mean value, because then the characteristic features of the day and night are medium."[13]

Āryabhaṭa II[14] (c. 950) and Bhāskara II[15] have prescribed the first result of Brahmagupta for all times. The method given in the *Sūrya-siddhānta*[16] is also essentially the same. The difference exists in form only.

According to Bhāskara II[17] the *sita* amounts to half when the Moon's longitude minus Sun's longitude is 85° 45′, not when it is 90° as presumed by the earlier astronomers. This means that he understood that the *sita* varies as the elongation of the Earth from the Sun (as seen from the Moon) and not as the Moon's longitude minus Sun's longitude. However, he has not stated this fact expressly, nor has he attempted to obtain the Earth's elongation from the Sun. Instead, he has applied a correction to the Moon in order to get the correct value of the *sita.*[18]

The astronomers who succeeded Bhāskara II have calculated the *sita* from the actual elongation of the Moon from the Sun and not from the difference between the Moon's longitude and the Sun's longitude. Since the actual elongation of the Moon from the Sun was the same as the angular distance between the discs of the Sun and Moon, these astronomers have called it *bimbāntara* ("the disc interval") and have calculated the *sita* by using it in place of the Moon's longitude minus Sun's longitude.

The *sita* really varies as the versed sine of the elongation of the Moon from the Sun (or more correctly as the versed sine of the elongation of the Earth from the Sun as seen from the Moon), not as the elongation of the Moon from the Sun (as measured on the ecliptic). So Brahmagupta's first result is gross and has been rightly criticized by the author of the *Valana-śṛṅgonnati-vāsanā.* "Brahmagupta and others (who have followed him)" says he, "have not considered the nature of the arc relation."[19] The rule given by Bhāskara I, however, is fairly good for practical purposes.

SPECIAL RULES

Muñjala (932), the author of the *Laghu-mānasa*, gives the following ingenious rule :

"The number of *karaṇas* elapsed since the beginning of the (current) fortnight diminished by two and then (the difference obtained) increased by one-seventh of itself, gives the measure of the *sita* if the fortnight is white or the *asita* if the fortnight is dark."[10]

That is :

$$sita = (K-2)\ (1+1/7)\ \textit{aṅgulas},$$

where K denotes the number of *karaṇas* elapsed in the light fortnight, the diameter of the Moon being assumed to be 32 *aṅgulas*.

As the Moon is visible only when it is at the distance of 12 degrees from the Sun, i.e. when 2 *karaṇas* have just elapsed, so the proportion is made here with $180-12=168$ degrees, instead of 180 degrees. If M and S denote the longitudes of the Moon and the Sun in terms of degrees, the proportion implied is: "When $M-S-12$ degrees amount to 168 degrees, the measure of the *sita* is 32 *aṅgulas*, what will be the measure of the *sita* when $M-S-12$ degrees have the given value?" The result is:

$$sita = \frac{(M-S-12) \times 32}{168} = \left(\frac{M-S}{6} - 2\right) (1+1/7)$$
$$= (K-2)\ (1+1/7)\ \textit{aṅgulas}.$$

Similar is the rule stated by Gaṇeśa Daivajña (1520) :

"The number of *tithis* elapsed in the light fortnight diminished by one-fifth of itself gives the measure of the *sita*.[11]

That is :

$$sita = (1-1/5)\,T\ \textit{aṅgulas},$$

T being the number of *tithis* elapsed in the light fortnight and the Moon's diameter being assumed to be equal to 12 *aṅgulas*.

Gaṇeśa Daivajña has applied proportion with the *tithis* elapsed in the light fortnight. His proportion is: "When on the expiry of 15 *tithis* the *sita* amounts to 12 *aṅgulas*, what will it amount to on the expiry of T *tithis*?" The result is :

$$sita = \frac{12\,T}{15} = (1-1/5)\ T\ \textit{aṅgulas}.$$

Both the above rules are approximate.

It will be noticed that Gaṇeśa Daivajña's formula is the same as the first result of Brahmagupta. The difference is in form only.

Graphical Representation of the Sita

The Indian astronomers have also stated rules to exhibit the *sita* graphically. It enabled them to know which of the two lunar horns was higher than the other at the time of the Moon's first visibility, the knowledge of which is of importance in natural astrology.

Bhāskara I and other early astronomers have exhibited the *sita* by projecting the Sun and Moon in the plane of the observer's meridian. They have first constructed a rightangled triangle *MAS*, in which *S* denotes the projection of the centre of the Sun, *M* the projection of the centre of the Moon, and *MA* the projection of the altitude-difference of the Sun and Moon, all in the plane of the observer's meridian. *AS*, the horizontal side of this triangle, is called the base; *MA*, the vertical side, the perpendicular or upright; and *MS*, the hypotenuse.

Describing how the construction of the *sita* is to be done at sun-set in the first quarter of the lunar month, Bhāskara I says :

"Lay off the base from the Sun in its own direction. (Then) draw a perpendicular-line passing through the head and tail of the fish-figure constructed at the end (of the base). (This) perpendicular should be taken equal to the *R* sine of the Moon's altitude and should be laid off towards the east. The hypotenuse-line should (then) be drawn by joining the ends of that (perpendicular) and the base.

"The Moon is (then) constructed by taking the meeting point of the hypotenuse and the perpendicular as centre (and the semi-diameter of the Moon as radius); and along the hypotenuse (from the point where it intersects the periphery of the Moon) is laid off the *sita* towards the interior of the Moon.

"The hypotenuse (indicates) the east and west directions; the north and south directions should be determined by means of a fish-figure. (Thus are obtained the three points, viz.) the north point, the south point, and a third point obtained by laying off the *sita*. (Now) with the help of two fish-figures constructed by the method known as *triśarkarāvidhāna* draw the circle passing through the (above) three points. Thus is shown, by the elevation of the lunar horns which are illuminated by the light between two circles, the Moon which destroys the mound of darkness by her bundle of light."[12]

Fig. 8.1 illustrates how the construction is made at sunset in the first quarter of the month. *A S* and *M* are the projections of the centres of the Sun and Moon in the plane of the observer's meridian, and *MA* the projection of the Moon's altitude in the same plane.

The triangle *MAS* is right-angled at *A*, *SA* is called the base, *MA* the perpendicular or upright, and *MS* the hypotenuse of this triangle. In the present case the base

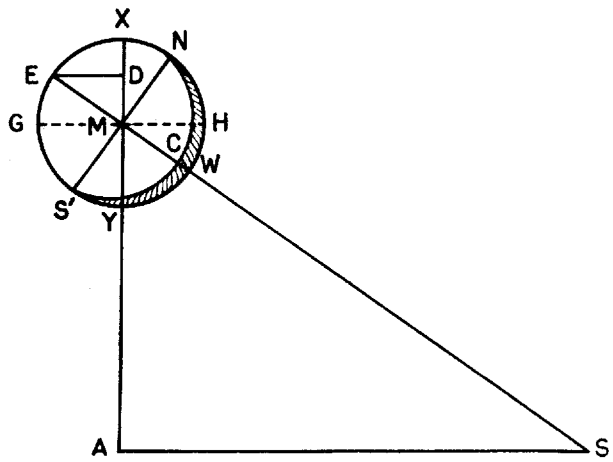


Fig. 8.1.

lies to the south of the Sun and the upright to the east of the base. The circle centred at M is the Moon's disc, i.e. the projection of the Moon's globe in the plane of the observer's meridian. The point W where MS intersects it is the west point of the Moon's disc. E, N and $\acute{S}$ are the east, north and south points. WC is the *Sita* which has been laid off, in the present case, from the west point W towards the interior of the Moon's disc. $NC\acute{S}$ is the circle drawn through N, C and $\acute{S}$. The shaded portion of the Moon's disc between the circles $NW\acute{S}$ and $NC\acute{S}$ is the illuminated part of the Moon's disc; the remaining part of the Moon's disc does not receive light from the Sun and remains dark *(asita)* and invisible.

Let GH be drawn perpendicular to MA through M. Then the Moon's horn which is intersected by it lies to the north of the upright MA. This is the higher horn. The elevation of this higher horn is measured by the angle NMH. The other horn, viz. $C\check{S}W$, which is not intersected by GH is the lower one. It lies to the south of the upright MA. So in the present case the northern horn is the higher one.

If the figure be held up with MA in the vertical position, the Moon in the sky will look like the shaded portion in the figure. This is what was intended.

The author of the *Sūrya-siddhānta* has followed the method of Bhāskara I. Describing the construction of the *sita,* at sun-rise in the last quarter of the month, he says:

> "Set down a point and call it the Sun. From it lay off the base in its own direction. From the extremity of that lay off the upright towards the west. Next draw the hypotenuse by joining the extremity of the upright and the point assumed as the Sun. Taking the junction of the upright and the hypotenuse as centre and the semi-diameter of the Moon at that time as the radius, draw the Moon's disc. Now with the help of the hypotenuse (assumed as the east-west line), first deter-

mine the directions (relative to the Moon's centre). From the point where the hypotenuse intersects the Moon's disc lay off the *sita* towards the interior of the Moon's disc. Between the point at the extremity of the *sita* and the north and south points draw two fish-figures. From the point of intersection of the lines going through them (taken as centre) draw an arc of a circle passing through the three points. As the Moon looks (in the figure) between this arc and the eastern periphery of the Moon's disc, so it looks in the sky that day. If the directions are determined with the help of the upright, the horn which is intersected by the line drawn at right angles to the upright through the Moon's centre is the higher one. The shape of the Moon should be demonstrated by holding up the figure keeping the upright in a vertical position."[23]

The construction given by Lalla is more general. He says :

"Take a point on the level ground and assume it to be the Sun. From this point lay off the base in its own direction (north or south). From the point reached lay off the upright. If the Moon is in the eastern hemisphere, the upright should be laid off towards the western direction; if the Moon is in the western hemisphere, it should be laid off towards the east. The hypotenuse should then be drawn by joining the extremity of the upright and the point assumed as the Sun. The Moon's disc should (then) be drawn by taking the junction of the hypotenuse and the upright as the centre. The hypotenuse-line here goes from west to east. The remaining (north and south) directions should be determined by means of a fish-figure. All this should be drawn very clearly with chalk. From the west point lay off the *sita* in the light fortnight or the *asita* in the dark fortnight (towards the interior of the Moon's disc). Taking the point thus reached, as also the north and south points (on the Moon's disc) as the centre draw two fish-figures. Where the mouth-tail lines of these fish-figures meet. taking that as the centre draw a neat circle passing through the *sita*-point inside the Moon's disc to exhibit the illuminated portion of the Moon. The direction in which the *aṅgulas* of the base have been laid off gives the direction of the depressed horn; the other horn is the elevated one."[14]

Āryabhaṭa II and Bhāskara II have omitted the construction of the triangle *MAS*. They have drawn the Moon directly with any point in the plane of the horizon as centre. Then they draw the direction-lines, i.e. the east-west and north-south lines. Assuming the north-osuth line as the same as the line *XY* of Fig. 8.1, they lay off *ED* (drawn orthogonally to the upright) which they call *digvalana* ("direction-deflection"). Having thus obtained the point *E* they draw *EW*, the line joining the Sun and Moon. After this their procedure is the same as that of Bhāskara I. The ***digvalana ED*** is evidently equal to

$$\frac{SA \times \text{Moon's diameter}}{MS}$$

which follows from the comparison of the similar triangles *MED* and *MAS*. See Fig. 8.1.

Brahmagupta does not project the Sun and Moon in the plane of the observer's meridian or any other plane. He keeps them where they are. So in the triangle *MAS*, which he constructs, *M* and *S* denote the actual positions of the centres of the Sun and Moon; *AS* is parallel to the north-south line of the horizon, and *MA* is perpendicular from *M* on this line. The Moon's disc is drawn in the plane of *MAS* with *M* as the centre. The laying off of the *sita* and the construction of the inner boundary of the *sita* is done as before.

Brahmagupta has been followed by Lalla and Śrīpati. Vaṭeśvara too follows Brahmagupta except in the case of sun-set or sunrise where he follows Bhāskara I.

Bhāskara II has pointed out a fallacy in the method of Brahmagupta. He says: "When the *sita* of the Moon is graphically shown in the way taught by him, using his base and hypotenuse, the lunar horns (shown in the figure) will not look like those seen in the sky. This is what I feel. Those proficient in astronomy should also observe it carefully. For, at a station in latitude 66°, the ecliptic coincides with the horizon and when the Sun is at the first point of Aries and the Moon at the first point of Capricorn the Moon appears vertically split into two halves by the observer's meridian and its eastern half looks bright. But this is not so in the opinion of Brahmagupta, for his base and upright are then equal to the radius. Actually, the tips of the lunar horns fall on a horizontal line when there is absence of the base, and on a vertical line when there is absence of the upright. Brahmagupta's base and upright then are both equal to the radius. Or, be as it may; I am not concerned. I bow to the great."[25]

Gaṇeśa Daivajña does not see any utility of the *parilekha* (graphical representation of the Moon). When from the direction of the *(dig) valana* itself, one can know which horn is high and which low, then, asks he, what is the use of the *parilekha*?[26]

The Visible Moon

In the present problem, we are concerned with the actual Moon and not with its calculated position on the ecliptic. The Indian astronomers have found it convenient to use, in place of the actual Moon, that point of the ecliptic which rises or sets with the actual Moon. This point of the ecliptic is called "the visible Moon" *(dṛśya-candra)*. This is derived from the calculated true Moon by applying to the latter a correction known as the visibility correction *(dṛkkarma* or *darśana-saṃskāra)*. The early astronomers, from Āryabhaṭa I to Bhāskara II, have applied two visibility corrections, viz. the *ayana-dṛkkarma* and the *akṣa-dṛkkarma*. The former is the portion of the ecliptic that lies between the secondaries to the ecliptic and the equator going through the actual Moon, and the latter is the portion of the ecliptic that lies between the horizon and the secondary to the equator going through the actual Moon, the actual Moon being supposed to be on the horizon.

Āryabhaṭa I gives the following rule for deriving the above-mentioned visibility corrections :

"Multiply the R versed-sine of the Moon's (tropical) longitude (as increased by three signs) by the Moon's latitude and also by the (R sine of the Sun's) greatest declination and divide (the resulting product) by the square of the radius: (the result is the *ayana-dṛkkarma* for the Moon). When the Moon's latitude is north, it should be subtracted from or added to the Moon's longitude, according as the Moon's *ayana* is north or south (i.e. according as the Moon is in the six signs beginning with tropical sign Capricorn or in the six signs beginning with the tropical sign Cancer); When the Moon's latitude is south, it should be added or subtracted (respectively)."[27]

"Multiply the R sine of the latitude of the local place by the Moon's latitude and divide (the resulting product) by the R sine of the co-latitude: (the result is the *akṣa-dṛkkarma* for the Moon). When the Moon is to the north (of the ecliptic), it should be subtracted from the Moon's longitude (as corrected for the *ayana-dṛkkarma*) in the case of the rising of the Moon and added to the Moon's longitude in the case of the setting of the Moon; when the Moon is to the south (of the ecliptic), it should be added to the Moon's longitude (in the case of the rising of the Moon) and subtracted from the Moon's longitude (in the case of the setting of the Moon)."[28]

If β be the Moon's latitude and M the Moon's tropical longitude, then the above rules are equivalent to the following formulae:

$$\textit{ayana-dṛkkarma} = \frac{R \text{ versin } (M+90^\circ) \times \beta \times R \sin 24^\circ}{R \times R} \quad (1$$

and

$$\textit{akṣa-dṛkkarma} = \frac{R \sin \phi \times \beta}{R \cos \phi} \quad (2)$$

ϕ being the latitude of the place and 24° being the Indian value of the Sun's greatest declination.

The same formulae occur in the works of Lalla,[29] Vaṭeśvara[30] and Śrīpati.[31]

These formulae are approximate and were modified by the later astronomers. Brahmagupta[32] replaced (1) by the better formula :

$$\textit{ayana dṛkkarma} = \frac{R \sin (M+90^\circ) \times \beta \times R \sin 24^\circ}{R \times R}.$$

This formula reappears in the *Mahā-siddhānta*[33] of Āryabhaṭa II in the form :

$$\textit{ayana-dṛkkarma} = \frac{R \cos M \times \beta \times R \sin 24^\circ}{R \times R}.$$

Śripati, while retaining the use of the R versed-sine, has improved (1) by multiplying it by 1800 and dividing by the *asus* of the rising of the sign occupied by the Moon.[34] (The *asus* are the minutes of arc of the equator).

Bhāskara II has criticized the use of the R versed-sine and has applauded Brahmagupta for replacing the R versed-sine by the R sine. He has also given the following new formulae:[35]

$$\text{(i) } \textit{ayana-dṛkkarma} = \frac{R \sin\,(\textit{ayanavalana}) \times \beta}{R \cos\,\delta} \times \frac{1800}{T}$$

where the *ayanavalana* is the angle between the secondaries to the equator and the ecliptic going through the Moon, δ the Moon's declination, and T the time of rising (in *asus*) of the sign occupied by the Moon.

$$\text{(ii) } \textit{ayana-dṛkkārma} = \frac{R \sin\,(\textit{ayanavalana}) \times \beta}{R \cos\,(\textit{ayanavalana})}$$

Formula (2) was modified by Bhāskara II. For his modified formulae the reader is referred to his *Siddhānta-śiromaṇi* (Part I, ch. vii, vss. 3, 6-8 and Part II, ch. ix, vs. 10).

Altitudes of Sun and Moon

To determine the Sun's altitude for the given time one has to know the Sun's ascensional difference and the earthsine. The Sun's ascensional difference is the difference between the times of rising of the Sun at the equator and at the local place. It is measured by the *asus* (minutes of equator) lying between the hour circle through the east point (called the six O'clock circle) and the hour circle through the rising Sun. The formula used to obtain it is :

$$R \sin c = \frac{R \sin \phi \times R \sin \delta \times R}{R \cos \phi \times R \cos \delta}$$

or, in modern notation,

$$\sin c = \tan \phi \tan \delta,$$

where c denotes the ascensional difference, δ the declination, and ϕ the latitude of the place.

The Sun's declination is obtained by the formula :

$$R \sin \delta = \frac{R \sin \lambda \times R \sin 24^\circ}{R}$$

where λ is the Sun's tropical longitude and 24° the Indian value of the obliquity of the ecliptic.

The earthsine is the R sine of c reduced to the radius of the diurnal circle and is obtained by the formula :

$$\text{earthsine} = \frac{R \sin c\; R \cos \delta}{R} = \frac{R \sin \phi\; R \sin \delta}{R \cos \phi}.$$

The Sun's ascensional difference and the earthsine being thus known, the Sun's altitude can be determined. Bhāskara I gives the following rule to find the Sun's altitude when the time elapsed since sunrise in the forenoon or to elapse before sunset in the afternoon is known :

> "The *ghaṭīs* elapsed (since sun-rise) or those to elapse (before sun-set), in the first half and the other half of the day (respectively), should be multiplied by 60 and again by 6: then they (i.e. those *ghaṭīs*) are reduced to *asus*. (When the Sun is) in the northern hemisphere, the *asus* of the Sun's ascensional difference should be subtracted from them and (when the Sun is) in the southern hemisphere, the *asus* of the Sun's ascensional difference should be added to them. (Then) calculate the R sine (of the resulting difference or sum) and multiply that by the day-radius (i.e. by $R \cos \delta$). Then dividing that (product) by the radius, operate (on the quotient) with the earthsine contrarily to the above (i.e. add or subtract the earthsine according as the Sun is in the northern or southern hemisphere). Multiply that (sum or difference) by the R sine of the co-latitude and divide by the radius: the result is the R sine of the Sun's altitude."[36]

> "When the Sun's ascensional difference cannot be subtracted from the given (time reduced to) *asus*, reverse the subtraction (i.e. subtract the latter from the former) and with the R sine of the remainder (proceed as above). In the night the R sine of the Sun's altitude should be obtained contrarily (i.e. by reversing the laws of addition and subtraction)."[37]

That is, when the Sun is in the northern hemisphere,

$$R \sin a = \frac{[\{R \sin (T \mp c)\ R \cos \delta)\}\ /R \pm \text{earthsine}]\ R \cos \phi,}{R}$$

where a denotes the Sun's altitude, δ the Sun's declination, T the time elapsed since sunrise in the forenoon or to elapse before sun-set in the afternoon (reduced to *asus*), c the Sun's ascensional difference (in *asus*), and ϕ the local latitude, the sign $+$ or $\sim$ being chosen properly, depending on the Sun's position.

In Fig. 8.2, which represents the celestial sphere for a place in latitude ϕ, $S'ENW$ is the horizon, E, W, N and S' being the east, west, north and south points; Z is the zenith. RER' is the equator and P its north pole. S is the Sun and LSM its diurnal circle. VU' is the Sun's rising-setting line and EW the east-west line. SA is the perpendicular from the Sun on the plane of the horizon and SB on the rising-setting line; AB is perpendicular to the rising-setting line. C is the point where AB intersects EW. SA is the R sine of the Sun's altitude, AB is the Sun's *śaṅkutala*, CB the Sun's *agrā*, AC the Sun's *bhuja*, and SB the Sun's *iṣṭahṛti*.

It can be easily seen that

$$SB = \{R \sin (T - c)\ R \cos \delta\}\ /R + \text{earthsine},$$

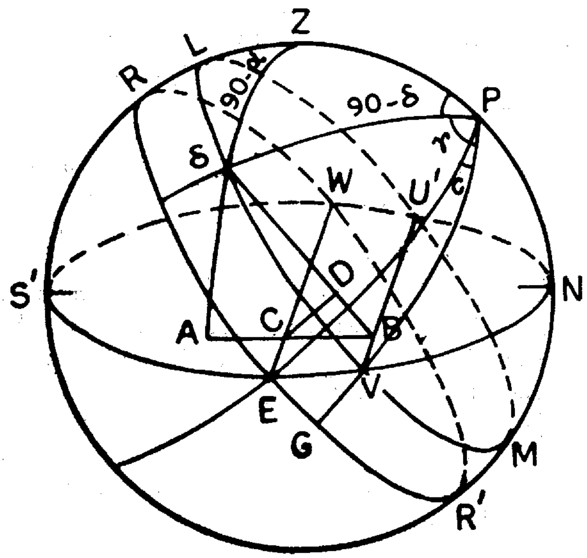


Fig. 8.2.

so that from the triangle SAB, right-angled at A, in which $\angle\ SAB = 90° — \phi$, we easily have

$$SA \text{ or } R \sin a = \frac{SB \times R \cos \phi}{R}$$

$$= \frac{[\{R \sin (T—c)\ R \cos\ \delta\}\ /R + \text{earthsine}]\ R \cos \phi}{R}.$$

Using modern spherical trigonometry, the rationale of this rule is as follows :

In Fig. 8.2, $\angle VPS = T$ and $\angle VPE = c$, so that $\angle EPS = T - c$, and likewise $\angle ZPS = 90° - (T - c)$. Now in the spherical triangle ZPS, we have $ZS = 90° - a$, $ZP = 90° - \phi$, $SP = 90° - \delta$, and $\angle ZPS = 90° - (T - c)$. Therefore, using cosine formula, we have

$$\cos ZS = \cos ZP \cos SP + \sin ZP \sin SP \cos \angle ZPS$$

or $\sin a = \sin \phi \sin \delta + \cos \phi \cos \delta \sin (T - c)$, and multiplying by R and re-arranging,

$$R \sin a = \frac{[\{R \sin (\ T - c)\ R \cos \delta\}\ /R + R \sin \phi\ R \sin \delta\ /R \cos \phi]\ R \cos \phi}{R}$$

$$= \frac{[R \sin (T - c)\ R \cos\ \delta\}\ /R + \text{earthsine}]\ R \cos \phi}{R}.$$

This is true when the Sun is in the northern heimsphere and above the horizon. Similar rationale may be given when the Sun is in the southern hemisphere or below the horizon.

The Moon's altitude is obtained in the same way. But in this case one has to use the Moon's true declination, i.e. the declination of the actual Moon. For this, in the present context, the early Indian astronomers, from Āryabhaṭa I to Bhāskara II, use the following approximate formula :

$$\text{Moon's true declination} = \delta \underset{s}{+} \beta,$$

where δ is the declination of the Moon's projection on the ecliptic and β the Moon's latitude.

In place of the time elapsed since sun-rise or to elapse before sunset, one has to use the time elapsed since moon-rise or to elapse before moon-set. The methods used to find the time of moon-rise or moon-set will be described in the next chapter.

Base and Upright

The base SA of the triangle MAS (in Fig. 8.1) is equal to the difference or sum of the Sun's *bhuja* and the Moon's *bhuja*. In case the Sun and the Moon are both above the horizon, the difference is taken provided the Sun and Moon are on the same side of the east-west line; otherwise the sum is taken. The *bhuja* of a heavenly body is defined by the distance of its projection on the plane of the horizon from the east-west line, so that

bhuja = distance of projection from the east-west line

= distance of projection from the rising-setting line (called *śaṅkutala* or *śaṅkvagra*) $\underset{s}{+}$ distance between the east-west and rising-setting lines (called *agrā*)

= *śaṅkutala* $\underset{s}{+}$ *agrā*.

In Fig. 8.2, S is the Sun. A is the Sun's projection on the plane of the horizon, AB is the Sun's *śaṅkutala*, CB is the Sun's *agrā*, and AC the Sun's *bhuja*. It is evident from the figure that in this case

$$AC = AB - CB$$

i.e. Sun's *bhuja* = Sun's *śaṅkutala* — Sun's *agrā*.

The Sun's *śaṅkutala* AB is obtained from triangle SAB (of Fig. 8.2) by using the sine relation :

$$AB \text{ or Sun's } \textit{śaṅkutala} = \frac{SA \times R \sin \angle ASB}{R \sin \angle SBA}$$

$$= \frac{R \sin a \times R \sin \phi}{R \cos \phi}.$$

Bhāskara I says :

"The R sine of the Sun's altitude multiplied by the R sine of the latitude and

divided by the R cosine of the latitude is the (Sun's) *śaṅkvagra,* which is always to the south of the rising-setting line."[38]

The Sun's *agrā* is obtained thus: In Fig. 8.2, let CD be the perpendicular from C to SB. Then in the triangle CDB, right-angled at D, CB = Sun's *agrā,* $CD = R \sin \delta$, $\angle CBD = 90^\circ - \phi$, so that

$$CB \text{ or Sun's } agr\bar{a} = \frac{AD \times R \sin \angle CDB}{R \sin \angle CBD}$$

$$= \frac{R \sin \delta \times R}{R \cos \phi}$$

Brahmagupta says :

"The R sine of the declination multiplied by the radius and divided by the R sine of the co-latitude is the *agrā* which lies east-west in the plane of the horizon."[39]

The Moon's *bhuja* is obtained in the same way, using the Moon's true declination. The difference or sum of the Moon's *bhuja* and Sun's *bhuja* finally gives the base.

When the calculations are made for sunset, the Sun's *agrā* itself is the Sun's *bhuja.* In that case, the difference or sum of the Moon's *bhuja* and the Sun's *agrā* gives the base.

Bhāskara I says :

"From the *asus* intervening between the Sun and Moon (corrected for the visibility corrections) and from the Moon's earthsine and ascensional difference, determine the R sine of the (Moon's) altitude; and from that find the (Moon's) *śaṅkvagra,* which is always south (of the rising-setting line of the Moon).

"The R sine of the difference or sum of the (Moon's) latitude and declination according as they are of unlike or like directions is (the R sine of) the Moon's true declination. From that (R sine of the Moon's true declination) determine her day-radius, etc. Then multiply (the R sine of) the Moon's (true) declination by the radius and divide by (the R sine of) the co-latitude: then is obtained (the R sine of) the Moon's *agrā.*

"If that (R sine of the Moon's *agrā*) is of the same direction as the (Moon's) *śaṅkvagra,* take their sum; otherwise, take their difference. Thereafter take the difference of (the R sine of) the Sun's *agrā* and that (sum or difference), if their directions are the same; otherwise, take their sum: thus is obtained the *base* (*bāhu* or *bhuja*)."[40]

The difference of the R sines of the Moon's altitude and the Sun's altitude during the day or their sum during the night, obviously, gives the upright, When the

calculations are made for sun-set, the R sine of the Moon's altitude itself is the upright, as the Sun then is on the horizon and its altitude is zero.

The base and upright obtained in the above way are according to those astronomers who, like Bhāskara I, project the Sun and Moon in the plane of the meridian. Brahmagupta and his followers, who keep the Sun and Moon where they are, obtain their base and upright, which shall be called Brahmagupta's base and upright, thus:

Brahmagupta's base $= b \overset{+}{\sim} b'$

Brahmagupta's upright $= \sqrt{(k \overset{+}{\sim} k')^2 + (R \sin a \overset{+}{\sim} R \sin a')^2}$, where b, b'; k, k'; a, a' are the *bhujas,* uprights and altitudes of the Sun and Moon respectively, derived in the manner described above.

It will be noted that whereas Brahmagupta's upright differs in length from that of Bhāskara I, his base is exactly equal to that of the latter.

RISING AND SETTING OF PLANETS AND STARS

Heliacal Rising and Setting of the Planets

When a planet gets near the Sun, it is lost in the dazzling light of the Sun and becomes invisible. The planet is then said to set heliacally. Sometimes later the planet comes out of the dazzling light and is seen again. It is then said to rise heliacally. In the case of the Moon, a special term *candra-darśana* ("Moon's first appearance") is used for its heliacal rising.

Brahmagupta says :

"A planet with lesser longitude than the Sun rises in the east, in case it is slower than the Sun; in the contrary case, it sets in the east. A planet with greater longitude than the Sun rises in the west, in case it is faster than the Sun; and sets in the west, in case it is slower than the Sun."[41]

The author of the *Sūrya-siddhānta* says :

"Jupiter, Mars, and Saturn, when their longitude is greater than that of the Sun, go to their setting in the west; when it is lesser, to their rising in the east; so likewise Venus and Mercury, when retrograding. The Moon, Mercury, and Venus, having a swifter motion, go to their setting in the east when of lesser longitude than the Sun; when of greater, go to their rising in the west."[42]

Vaṭeśvara's account is fuller and more explicit:

"A planet with lesser longitude (than the Sun) rises in the east if it is slower than the Sun; and sets in the east if it is faster than the Sun; whereas a planet with

greater longitude (than the Sun) rises in the west if it is faster than the Sun, and sets in the west if it is slower than the Sun.

"The Moon, Venus, and Mercury rise in the west, whereas Saturn, Mars, and Jupiter and also retrograding Mercury and Venus rise in the east. These planets set in the opposite direction."[43]

Similar statements have been made by Lalla,[44] Āryabhaṭa II,[45] Śrīpati,[46] Bhāskara II[47] and others.

The distances from the Sun at which the heliacal rising or setting occurs is not the same for all the planets. It depends upon the size and luminosity of the planet. The larger or more luminous it is, the lesser will be its distance from the Sun at the time of its rising or setting.

The Indian astronomers state the distances of the planets from the Sun at the time of their first visibility ("rising") or last visibility ("setting") in terms of time-degrees, i.e. in terms of time, between the time of rising or setting of the planet and that of the Sun, converted into degrees by the formula :

60 *ghaṭīs* or 24 hours = 360 degrees.

Āryabhaṭa I says :

"When the Moon has no latitude it is visible when situated at a distance of 12 degrees (of time) from the Sun. Venus is visible when 9 degrees (of time) distant from the Sun. The other planets taken in the order of decreasing sizes (viz. Jupiter, Mercury, Saturn, and Mars) are visible when they are 9 degrees (of time) increased by two-s (i.e. when they are 11, 13, 15 and 17 degrees of time) distant from the Sun."[48]

The same distances have been given in the *Āryabhaṭa-siddhānta* and the *Khaṇḍakhādyaka,*[49] and by Brahmagupta,[50] Lalla,[51] Vaṭeśvara,[52] and Śrīpati.[53] Those given by Āryabhaṭa II,[54] Bhaskara II,[55] and by the author of the *Sūrya-siddhānta*[56] slightly differ in one or two cases.

Regarding Venus and Mercury, Brahmagupta says :

"Owing to its small disc, Venus (in direct motion) rises in the west and sets in the east at a distance of 10 time-degrees (from the Sun); and owing to its large disc, the same planet (in retrograde motion) sets in the west and rises in the east at a distance of (only) 8 time-degrees (from the Sun). Mercury rises and sets in a similar manner when its distance (from the Sun) is 14 time-degrees (in the case of direct motion) or 12 time-degrees (in the case of retrograde motion)."[57]

So has been said by the author of the *Sūrya-siddhānta*[58] and Śrīpati.[59]

Time-degrees for heliacal rising and setting

Celestial body	Time-degrees according to				
	Āryabhaṭa I	Brahmagupta	Lalla and Vaṭeśvara	Āryabhaṭa II	*Sūrya-siddhānta* and Bhāskara II
Moon	12°	12°	12°	12°	12°
Mars	17°	17°	17°	17°	17°
Mercury	13°	13° (mean), 14°	13°	13°	14°
Mercury (retro)		12°	12°	12°30′	12°
Jupiter	11°	11°	11°	12°	11°
Venus	9°	9° (mean) 10°	9°	8°	10°
Venus (retro)		8°	8°	7°30′	8°
Saturn	15°	15°	15°	15°	15°

To find the day on which a planet is to rise or set heliacally in the east or west, the Indian astronomers proceed as follows: In the case of rising or setting in the east, they first calculate for sunrise the longitudes of the Sun and the planet, the latter being corrected by the visibility corrections for rising. Then, using the table giving the times of rising of the signs for the local place, they calculate the time of rising of the portion of the ecliptic lying between the Sun and the corrected planet. This they convert into time-degrees, and then find the difference between these time-degrees and the time-degrees for rising or setting of the planet under consideration. If the planet is in direct motion they divide this difference by the degrees of difference between the daily motions of the Sun and the planet; and if the planet is in retrograde motion they divide that difference by the degrees of the sum of the daily motions of the Sun and the planet. The quotient obtained gives the days elapsed since or to elapse before the rising or setting of the planet in the east.

In the case of rising or setting in the west, they first calculate for sun-set the longitudes of the Sun and the planet, the latter corrected by the visibility corrections for setting. Both these longitudes are increased by six signs. Then, using the table giving the times of rising of the signs for the local place, they calculate the time of rising of the portion of the ecliptic lying between the Sun as increased by six signs and the corrected planet as increased by six signs. This they convert into time-degrees, and find the differenee between these time-degrees and the time-degrees for rising or setting of the planet under consideration. If the planet is in direct motion they divide this difference by the degrees of difference between the daily motions of the Sun and the planet; and if the planet is in retrograde motion they divide that difference by the degrees of the sum of the

daily motions of the Sun and the planet. The quotient obtained gives, as before, the days elapsed since or to elapse before the rising or setting of the planet in the west.

Bhāskara I says :

"(When the planet is to be seen) in the east, (its) visibility should be announced by calculating the time (of rising of the part of the ecliptic between the Sun and the planet corrected by the visibility corrections) by using the time of rising at the local place of that very sign (in which the Sun and the planet are situated); (when the planet is to be seen) in the west, (its) visibility should be announced by calculating the time (of setting of the part of the ecliptic between the Sun and the planet) by using the time of rising of the seventh sign at the local place."[60]

Lalla describes the method as follows :

"(If the heliacal rising or setting of a planet) on the western horizon is considered, the true longitude of the Sun and the *dṛggraha* (i.e. the planet corrected by the visibility corrections for setting) should each be increased by six signs.

"Find the *asus* of rising of the untraversed part of the sign occupied by the planet with lesser longitude and the *asus* of rising of the traversed part of the sign occupied by the planet with greater longitude. To the sum of the two add the *asus* of rising of the intervening signs. The result divided by 60 gives the time-degrees of the planet's distance from the Sun. If these time-degrees are lesser than the time-degrees stated for the rising or setting of the planet, it must be understood that the planet is invisible.

"Find the difference expressed in minutes between the calculated time-degrees and the time-degrees for rising or setting of the planet. Divide it by (the minutes of) the difference of the daily motions of the Sun and the planet if they are moving in the same direction, or by (the minutes of) the sum if they are moving in opposite directions. The quotient gives the days elapsed since or to elapse before the rising or setting of the planet, which is to be understood by the following consideration.

"When the setting of a planet is considered, if the time-degrees for rising or setting of the planet are greater than the calculated time-degrees, know then that the planet has set heliacally before the number of days found above; if the former is lesser, the planet will set after so many days. When the rising is considered, then in the former case the planet will rise after the days calculated and in the latter case the planet has risen before the days calculated."[61]

Vaṭeśvara explains the method thus :

"In the case of rising in the east, find the *asus* of rising of the untraversed part of the sign occupied by the planet (computed for sunrise and corrected by the

visibility corrections for rising), those of the traversed part of the sign occupied by the Sun (at sunrise); and in the case of setting in the west, in the reverse order.[61] Add them to the *asus* of rising of the intervening signs. (Then are obtained the *asus* of rising of the part of the ecliptic lying between the planet corrected by the visibility corrections and the Sun at sunrise. These divided by 60 give the time-degrees between the planet corrected by the visibility corrections and the Sun).

"(To obtain the time-degrees corresponding to the traversed and untraversed parts), one should multiply the untraversed and traversed degrees by the *asus* of rising of the corresponding signs and divide (the products) by 30 and 60 (i.e. by 1800). The time-degrees divided by 6 give the corresponding *ghaṭis*.

"When the time-degrees between the planet corrected by the visibility corrections and the Sun are greater than the time-degrees for the planet's rising or setting, it should be understood that the planet has already risen (heliacally); if lesser, the rising has not yet taken place.

"Divide their difference by the daily motion of the Sun diminished by the daily motion of the planet when the planet is in direct motion, and by the daily motion of the Sun increased by the daily motion of the planet when the planet is in retrograde motion: the result is the time (in days) which have to elapse before the planet will rise or set or elapsed since the rising or setting of the planet."[63]

Similar rules have been given by the other Indian astronomers.[64]

Heliacal Rising and Setting of the Stars

The stars having no motion rise in the east and set in the west. The distance from the Sun at which they rise or set heliacally, according to the Indian astronomers, is 14 time-degrees or $6\frac{1}{3}$ *ghaṭis*. In the case of Canopus (Agastya) this distance is 12 time-degrees or 2 *ghaṭis* and in the case of Sirius (Mṛgavyādha) it is 13 time-degrees or $2\frac{1}{6}$ *ghaṭis*. This is so because Canopus and Sirius are bright stars.

The point of the ecliptic which rises on the eastern horizon exactly when a star rises on the eastern horizon, is called the star's *udayalagna;* and the point of the ecliptic which rises on the eastern horizon exactly when a star sets on the western horizon, is called the star's *astalagna*. Similarly, the point of the ecliptic occupied by the Sun when a star rises heliacally is called the star's *udayārka* or *udayasūrya;* and the point of the ecliptic occupied by the Sun when a star sets heliacally is called the star's *astārka* or *astasūrya*.

The positions of the stars are given in terms of their polar longitudes. So only one visibility correction, viz. the *akṣa-dṛkkarma,* has to be applied to them. When the *akṣa-dṛkkarma* for rising is applied to the polar longitude of a star, one gets the star's

udayalagna; and when the *akṣa-dṛkkarma* for setting is applied to the polar longitude of a star and six signs are added to that, one gets the star's *astalagna*.

The *udayārka* for a star is obtained by calculating the *lagna* (the rising point of the ecliptic), by taking the Sun's longitude as equal to the star's *udayalagna* and the time elapsed since sunrise as equal to the *ghaṭis* of the star's distance from the Sun at the time of its heliacal rising. The *astārka* for a star is obtained by calculating the *lagna*, by taking the Sun's longitude as equal to the star's *astalagna* and the time to elapse before sunrise as equal to the *ghaṭis* of the star's distance from the Sun at the time of its heliacal visibility, and adding six signs to that.

Taking the case of Canopus and Sirius, Brahmagupta says :

"From the *udayalagna* of Canopus calculate the *lagna* at two *ghaṭis* after sunrise by means of the times of rising of the signs (at the local place). The result is the *udayasūrya* of Canopus. Again from the *astalagna* (of Canopus) calculate the *lagna* at two *ghaṭis* before sunrise, and add six signs to it. The result is the *astasūrya* of Canopus.

"In the same manner the *udayasūrya* and *astasūrya* of Sirius may be found. In this case $2\frac{1}{6}$ *ghaṭis* should be used.

"Similarly, the *udayasūrya* and *astasūrya* of other stars should be calculated. In this case $2\frac{1}{3}$ *ghaṭis* should be used.

"Canopus, Sirius or any of the (other) stars rises or sets according as its *udayasūrya* or *astasūrya* is the same as the true Sun."[65]

Lalla says :

"On account of the motion of the provector wind, the rising of a star occurs with the rising of its *udayalagna,* and the setting of a star occurs with the rising of its *astalagna.*

"Two *ghaṭis* plus one-third of a *ghaṭi* is the time-distance of a star from the Sun at the time of its heliacal rising or setting; that for Sirius, it is two *ghaṭis* plus one-sixth of a *ghaṭi;* and that for Canopus, it is two *ghaṭis.*

"The star whose *udayalagna* increased by the result due to that time-distance (i.e. by the arc of the ecliptic that rises in that time) happens to be equal to the Sun's longitude (at that time), rises heliacally; and the star whose *astalagna* diminished by the result due to that time-distance and also by six signs, happens to be equal to the Sun's longitude (at that time), sets heliacally."[66]

So also says Vaṭeśvara :

"When the longitude of the Sun is equal to the longitude of the star's *udayalagna* as increased by the result obtained on converting the 14 time-degrees for the

star's heliacal rising or setting into the corresponding arc of the ecliptic (which rises at the local place in that time), the star rises heliacally; and when the longitude of the Sun is equal to the longitude of the *astalagna* as diminished by the result due to the time-degrees for the star's heliacal rising or setting and by half a circle, the star sets heliacally.

"When the star's *udayalagna* or *astalagna* is at a lesser distance from the Sun, the star is invisible; in the contrary case, the star is visible."[67]

A similar statement has been made by Bhāskara II.[68]

As regards the duration of a star's visibility or invisibility, Brahmagupta says:

"A star is visible as long as the Sun lies between its *udayasūrya* and *astasūrya;* otherwise, it is invisible.

"Find the difference between the star's *udayasūrya* and the Sun, or between the *astasūrya* and the Sun. Express the difference in minutes. Divide each difference by the daily motion of the Sun. The result gives respectively the number of days passed since the heliacal rising of the star and those which will pass before the star sets heliacally."[69]

Lalla says :

"As long as the Sun is between the star's *udayārka* and *astārka,* so long is the Sun heliacally visible, provided that the star's declination diminished or increased by the local latitude according as they are of like or unlike directions, is less than 90°.

"As long as the Sun is between the star's *astasūrya* and *udayasūrya,* so long is the star heliacally invisible."

"The difference between the two (i.e. the star's *udayasūrya* minus the star's *astasūrya*) expressed in minutes, when divided by the true daily motion of the Sun, gives the days (for which the star is invisible)."[70]

Śrīpati says :

"As long as the Sun is between the star's *udayasūrya* and the star's *astasūrya,* so long is the star heliacally visible; and as long as the Sun is between the star's *astasūrya* and the star's *udayasūrya,* so long is the star invisible. The star, however, is seen as long as its zenith distance is less than 90°."[71]

Vaṭeśvara :

"Subtract the star's *astārka* from the star's *udayārka* and reduce the difference to minutes. Divide these minutes by the minutes of the Sun's daily motion.

Then is obtained the number of days during which the star remains set heliacally."[72]

Stars Always Visible Heliacally

The stars which are far away from the ecliptic do not fall prey to the dazzling light of the Sun. Such stars are always visible heliacally. The author of the *Sūrya-siddhānta* says :

"Vega (Abhijit), Capella (Brahmahṛdaya), Arcturus (Svātī), α Aquilae (Śravaṇa), β Delphini (Śraviṣṭhā), and λ Pegasi (Uttara-Bhādrapada), owing to their (far) northern situation, are not extinguished by the Sun's rays."[73]

These stars have large latitudes and in their case the *astasūrya* exceeds the *udayasūrya*. The latter is the condition for a star's permanent heliacal visibility.

Brahmagupta says :

"The star whose *udayārka* is smaller than its *astārka* is always visible."[74]

Lalla says :

"The star, whose *astārka* is greater than its *udayārka,* never sets heliacally."[75]

So also say the other Indian astronomers.[76]

Diurnal Rising and Setting

The rising of the heavenly bodies every day on the eastern horizon is called the diurnal rising of those heavenly bodies. Similarly the setting of the heavenly bodies on the western horizon is called their diurnal setting. It is this rising or setting that is meant when one talks of sun-rise or sun-set, moon-rise or moon-set.

The rising of the Sun does not present any difficulty, because it is taken as the starting point of time measurement. The rising and setting of the Moon are indeed of importance to the Indian astronomers. All astronomical works deal with them and give rules to find the time of moon-set or moon-rise in the light and dark fortnights of the month.

Bhāskara I gives the following rules to find the time of moon-set or moon-rise : "In the light fortnight, find out the *asus* due to oblique ascension (of the part of the ecliptic) intervening between the Sun (at sun-set) and the (visible) Moon (at sun-set treated as moon-set) both increased by six signs, and apply the method of successive approximations. This gives the duration of the visibility of the Moon (at night) (or, in other words, the time of moon-set)."[77]

"Thereafter (i.e. in the dark fortnight) the Moon is seen (to rise) at night (at the time) determined by the *asus* (due to oblique ascension) derived by

the method of successive approximations from the part of the ecliptic intervening between the Sun as increased by six signs and the (visible) Moon as obtained by computation, (the Sun and the Moon both being those calculated for sun-set)."[78]

Further he says :

"(In the light half of the month) when the measure of the day exceeds the *nāḍis* (due to the oblique ascension of the part of the ecliptic) lying between the Sun and the (visible) Moon (computed for sun-set), the moonrise is said to occur in the day when the residue of the day (i.e. the time to elapse before sun-set) is equal to the *ghaṭis* of their difference."[79]

"(In the dark half of the month) find out the *asus* due to the oblique ascension of the part of the ecliptic lying from the setting Sun up to the (visible) Moon; and therefrom subtract the length of the day. (This approximately gives the time of moon-rise as measured since sun-set). Since the Moon is seen (to rise) at night when so much time, corrected by the method of successive approximations, is elapsed, therefore the *asus* obtained above should be operated upon by the method of successive approximations."[80]

"Or, determine the *asus* (due to the oblique ascension of the part of the ecliptic lying) from the (visible) Moon at sun-rise up to the rising Sun; then subtract the corresponding displacements (of the Moon and the Sun) from them (i.e. from the longitudes of the visible Moon and the Sun computed for sun-rise); and on them apply the method of successive approximations (to obtain the nearest approximation to the time between the visible Moon and the Sun computed for moon-rise, i.e. between the risings of the Moon and the Sun). The Moon,. . . ., rises as many *asus* before sun-rise as correspond to the *nāḍis* obtained by the method of successive approximations."[81]

Bhāskara I has given the details of the implied processes of successive approximations also.

Vaṭeśvara gives the methods of finding out the time of moon-rise and moon-set thus :

"In the light half of the month the calculation of the time of rising of the Moon in the day is prescribed to be made from the positions of the Sun and the (visible) Moon (for sun-rise) in the manner stated before; and that of the time of setting of the Moon at the end of the day (i.e. at night) from the positions of the Sun and the (visible) Moon (for sun-set), both increased by six sings.

"In the dark half of the month, the (time of) rising of the Moon, when the night is yet to end, should be calculated by the process of iteration from the positions of the Sun and the (visible) Moon (for sun-rise); and in the light half of the

month, the (time of) rising of the Moon, when the day is yet to end, should be calculated by the process of iteration from the position of the Sun (for sun-set) increased by six signs and the position of the (visible) Moon (for sun-set).

"In the dark half of the month, the time of setting of the Moon, when the day is yet to elapse, should be obtained from the positions of the Sun and the (visible) Moon (for sun-set), each increased by six signs.

"In the light half of the month, the same time (of setting of the Moon), when the night is yet to elapse, should be obtained from the positions of the (visible) Moon (for sun-rise) increased by six signs and the position of the Sun (for sun-rise)."[82]

Similar methods have been prescribed by the other Indian astronomers also.

The phenomenon of moon-rise on the full moon day is of special importance and the Indian astronomers have dealt with this topic separately. Bhāskara I says :

"If (at sun-set) on the full moon day the longitude of the Moon (corrected for the visibility corrections for rising) agrees to minutes with the longitude of the Sun (increased by six signs), then the Moon rises simultaneously with sun-set. If (the longitude of the Moon is) less (than the other), the Moon rises earlier; if (the longitude of the Moon is) greater (than the other), the Moon rises later.

"(In the latter cases) multiply the minutes of the difference by the *asus* of the oblique ascension of the sign occupied by the Moon and divide by the number of minutes of arc in a sign, and on the resulting time apply the method of successive approximations (to get the nearest approximation to the time to elapse at moon-rise before sun-set or elapsed at moon-rise since sun-set)."[83]

Lalla says :

"If the true longitude of the Moon, (corrected for the visibility corrections for rising), is the same as the true longitude of the Sun at sun-set, increased by six signs, the Moon rises at the same time as the Sun sets; if greater, it rises later; and if less, it rises before sun-set.

If the true longitude of the Moon, (corrected for the two visibility corrections for setting) and increased by six signs, is the same as the true longitude of the Sun while rising, the Moon sets at that time; if greater, it sets after, and if less, before sun-rise."[84]

So also says Vaṭeśvara :

"When the true longitude of the Moon (for sun-set), (corrected for the visibility corrections for rising), becomes equal to the longitude of the Sun (for sun-set),

increased by six signs, then the Moon, in its full phase, resembling the face of a beautiful lady, rises (simultaneously with the setting Sun), and goes high up in the sky, glorifying by its light the circular face of the earth freed from darkness, making the lotuses close themselves and the water lilies blossom forth.

"On the full-moon day, at evening, the Sun and the Moon, stationed in the zodiac at the distance of six signs, appear on the horizon like the two huge gold bells (hanging from the two sides) of Indra's elephant."[85]

TIME-INTERVAL FROM RISING TO SETTING

In the case of the Sun, the time-interval from rising to setting is called the duration of sunlight or the duration of the day. Similarly, the time-interval from setting to rising is called the duration of the night. These are obtained by the formulae:

duration of day $= 2$ (15 *ghaṭis* $\pm$ *ghaṭis* of Sun's ascensional difference)

duration of night $= 2$ (15 *ghaṭis* $\mp$ *ghaṭis* of Sun's ascensional difference),

the upper of lower sign being taken according as the Sun is to the north or south of the equator.

Brahmagupta says :

"15 *ghaṭis* respectively increased and diminished when the Sun is in the northern hemisphere, or respectively diminished and increased when the Sun is in the southern hemisphere, by the *ghaṭis* of the Sun's ascensional difference, and the results doubled, give the *ghaṭis* of the durations of the day and night, respectively."[86]

Lalla says :

"When the Sun's ascensional difference expressed in *ghaṭis* is respectively added to and subtracted from 15 *ghaṭis*, and the results are doubled, the lengths of night and day are obtained, provided the Sun is in the southern hemisphere beginning with Libra. The same give the lengths of day and night, if the Sun is in the northern hemisphere beginning with Aries."[87]

So also has been stated by Śrīpati,[88] Bhâskara II,[89] and other Indian astronomers.

The duration from moon-rise to moon-set is called the length of the Moon's day and the duration from moon-set to moon-rise, the length of the Moon's night. The former is obtained by the formula:

length of Moon's day = time of rising of the untraversed portion of the sign occupied by the Moon's *udayalagna* + time of rising of the traversed portion of

the sign occupied by the Moon's *astalagna*+time of rising of the intermediate signs.

Vaṭeśvara says :

"The Moon's *udayalagna* increased by six signs gives the Moon's *astalagna*. Find the oblique ascension of that part of the ecliptic that lies between the two (i.e. between the Moon's *udayalagna* and *astalagna*) with the help of the oblique ascensions of the signs: (this gives the length of the Moon's day). The difference between half of it and 15 *ghaṭīs* is the Moon's ascensional difference."[90]

Vaṭeśvara's method of finding the Moon's *astalagna* is gross. For, here the motion of the Moon from moon-rise to moon-set has been neglected. The correct rule is: First find out the Moon's true longitude for the time of moon-rise; then increase it by half the Moon's daily motion; then apply to it the visibility corrections for setting; then and six signs to that: the result thus obtained will be the Moon's *astalagna*.

In the case of a planet or a star the length of the day is defined and obtained as in the case of the Moon.

Āryabhaṭa II gives the following rule to get a planet's *astalagna:*

"Calculate the true longitude of the planet for the time of its rising, apply to it one-half of the planet's daily motion, then correct it by the visibility corrections for the western horizon (i.e. for setting), and then add six signs to it. (The result is the planet's *astalagna*). Now find the time of rising of the travereed part of the decan occupied by it, to it add the time of rising of the untraversed part of the decan occupied by the planet's *udayalagna,* as also the times of rising of the intervening decans. The result is the length of the planet's day. Using this length of the planet's day, again calculate the true longitude of the planet for the time of its setting, and iterate the above process. Thus will be obtained the accurate longitude of the visible planet on the western horizon. That increased by six signs is the planet's *astalagna.*"[91]

The planet's *udayalagna* and *astalagna* being known, the length of the planet's day is obtained by adding together the time of rising of the untraversed portion of the decan (or sign) occupied by the planet's *udayalagna,* the time of rising of the traversed portion of the decan (or sign) occupied by the planet's *astalagna,* and the times of rising of the intervening decans (or signs).

In the case of the stars too the method used to find the length of the day is the same. The stars being fixed, their *udayalagna* and *astalagna* remain the same for years. Āryabhaṭa II says: "In the case of Canopus, the Seven Sages and the stars (in general) the *udayalagna* and the *astalagna* remain invariable for some years. Not so is the case with the evermoving planets, the Moon etc., because of their inconstancy."[92]

Stars That Do Not Rise Or Set (Circumpolar Stars)

The stars whose declination is greater than or equal to the co-latitude of the place do not rise or set at that place. If the declination is north, these stars are always visible at the place; if south, they are always invisible there.

Bhāskara II says :

"The stars for which the true declination, of the northern direction, exceeds the co-latitude (of the local place), remain permanently visible (at that place). And the stars such as Sirius and Canopus etc. for which the true declination, of the southern direction, exceeds the co-latitude (of the local place), remain permanently invisible (at that place)."[93]

CONJUNCTION OF PLANETS AND STARS

Conjunction Of Two Planets

Samāgama and Yuddha ("Union And Encounter")

When two planets have equal longitudes they are said to be in conjunction. This conjunction of two planets is given different names depending on the participating planets. When the conjunction of a planet takes place with the Sun, it is called *astamaya* (setting of the planet); when with the Moon, it is called *samāgama* (union); and when any two planets, excluding the Sun and Moon, are in conjunction, it is called *yuddha* (encounter).

Viṣṇucandra says :

"Conjunction (of a planet) with the Sun is called *astamaya* (setting); that with the Moon, *samāgama* (union); and that of Mars etc. with one another, *yuddha* (encounter)."[94]

Brahmagupta says :

"Conjunction (of two planets), in which the Sun and Moon do not take part, is called *yuddha* (encounter); that of Mars etc. with the Moon, *samāgama* (union); and that with the Sun, *astamaya* (setting). (In the case of encounter) the planet that lies to the north of the other is the victor; but Venus is the victor (even) when it is to the south of the other."[95]

According to the *Sūrya-siddhānta* :

"Of the star-planets (Mars etc.) there take place, with one another, *yuddha* (encounter) and *samāgama* (union); with the Moon, *samāgama* (union); with the Sun, *astamaya* (setting)."[96]

"(In an encounter) Venus is generally the victor, whether it lies to the north or to the south (of its companion)."[97]

The conjunction of two star-planets Mars etc. which has been defined above as *yuddha* (encounter), is further classified into five categories, depending on the distance between them at the time of their conjunction. Let d be the distance between their centres at the time of their conjunction, and s the sum of their semi-diameters.

Then the conjunction is called :

1. *Ullekha* (external contact), when $d = s$;
2. *Bheda* (occultation), when $d<s$;
3. *Aṃśu-vimarda* ("pounding or crushing of rays, friction of rays), when $d>s$;
4. *Apasavya* (dexter) when $d>s$ but $<1°$ and one planet is tiny;
5. *Samāgama* (union), when $d>s$ and also $>1°$ and the planets have large discs.

The *Sūrya-siddhānta* says :

"The conjunction of two star-planets is called *ullekha* (external contact), when they touch each other (externally); *bheda* (occultation), when there is overlapping; *aṃśu-vimarda* (pounding or crushing of rays, or friction of rays), when there is mingling of rays of each other; *apasavya-yuddha* (dexter), when one planet has tiny disc and the distance between the two is less than one degree; *samāgama* (union), when the discs of the planets are large and the distance between them is greater than one degree."[98]

The *Sūrya-siddhānta* further says :

"In the *apasavya yuddha* (dexter encounter) the star-planet which is tiny, destitute of brilliancy, and covered (by the rays of the other), is the defeated one. (In general) the star-planet which is rough, colourless, struck down, and situated to the south, is the vanquished one. That situated to the north is the victor if it is large and luminous; that situated to the south too is the victor if it is powerful (i.e. large and luminous). When two star-planets are in proximity, there is *samāgama* (union) if both are luminous; *kūṭa* (confrontation) if both are small in size; and *vigraha* (conflict, or fight) if both are struck down. Venus is generally the victor whether it is to the north or to the south (of the other).[99]

The *Bhārgavīya* says :

"Hostility should be foretold when there is *apasavya* (dexter); war when there is *raśmi-saṃkula* (melee of rays); ministerial distress when there is *ullekha* (external contact); and loss of wealth when there is *bheda* (occultation)."[100]

CONJUNCTION IN CELESTIAL LONGITUDE (KADAMBAPROTIYA-YUTI)

Āryabhaṭa I and his staunch follower Bhâskara I have dealt with the conjunction of the planets in celestial longitude (i.e. along the circle of celestial longitude or secondary to the ecliptic) and have given rules to find the time when such a conjunction occurs.

Bhāskara I says :

"If one planet is retrograde and the other direct, divide the difference of their longitudes by the sum of their daily motions; otherwise (i.e. if both of them are either retrograde or direct), divide the same by the difference of their daily motions; thus is obtained the time in terms of days etc. after or before which the two planets are in conjunction (in longitude). The velocity of the planets being different (from time to time), the time thus obtained is gross. One, proficient in the science of astronomy, should, therefore, apply some method to make the longitudes of the two planets agree to minutes. Such a method is possible from the teachings of the precepter or by day to day practice."[101]

"In the case of Mercury and Venus, subtract the longitude of the ascending node from that of the *śighrocca:* (thus is obtained the longitude of the planet as diminished by the longitude of the ascending node). The longitudes (in terms of degrees) of the ascending nodes of the planets beginning with Mars (i.e. Mars, Mercury, Jupiter, Venus and Saturn) are respectively 4, 2, 8, 6, and 10, each multiplied by 10.

"The greatest latitudes, north or south, in minutes of arc, (of the planets beginning with Mars) are respectively 9, 12, 6, 12, and 12, each multiplied by 10. (To obtain the *R* sine of the latitude of a planet) multiply (the greatest latitude of the planet) by the *R* sine of the longitude of the planet minus the longitude of the ascending node (of the planet) (and divide by the "divisor" defined below).

"The product of the *mandakarṇa* and the *śighrakarṇa* divided by the radius is the distance between the Earth and the planet: this is defined as the "divisor".

"Thus are obtained the minutes of arc of the latitudes (of the two planets which are in conjunction in longitude).

"From these latitudes obtain the distance between those two given planets (which are in conjunction in longitude) by taking their difference if they are of like directions or by taking their sum if they are of unlike directions. The true distance between the two planets, in minutes of arc, being divided by 4 is converted into *aṅgulas*.

"Other things should be inferred from the colour and brightness of the rays (of the two planets) or else by the exercise of one's own intellect."[102]

The method prescribed by Āryabhaṭa I in his work employing midnight day-reckoning was also practically the same. Brahmagupta has summarized it as follows:

"Divide the difference between the longitudes of the two planets (whose conjunction is under consideration) by the difference of their daily motions, if they are

both direct or both retrograde, or by the sum of their daily motions, if one is direct and the other retrograde. The result is in days. If the slower planet is ahead of the other (and if both the planets are direct), the conjunction is to occur after the days obtained; if the quicker planet is ahead of the other, the conjunction has already occurred before the days obtained.

"Multiply the difference between the longitudes of the two planets by their own daily motions and divide (each product) by the difference or sum of their daily motions, as before. Subtract each result from the longitude of the corresponding planet, if the conjunction has already occurred, and add, if it is to occur, provided the planet is in direct motion. If it is retrograde, reverse the order of subtraction and addition. The planets will then have equal longitudes.

"From the longitudes of the two planets made equal up to minutes of arc, subtract the longitudes of their own ascending nodes (in the case of Mars, Jupiter and Saturn). In the case of Mercury and Venus, the longitude of the ascending node should be subtracted from the *śighrocca* of the planet. Multiply the *R* sine of that by the greatest latitude of the corresponding planet and divide by the last *karṇa* ("hypotenuse for the planet"): the result is the latitude of the planet.

"Take the difference or sum of the latitudes of the two planets (which are in conjunction in longitude) according as they are of like or unlike directions. Then is obtained the distance between the planets (at the time of their conjunction in longitude)."[103]

Occultation (bheda-yuti)

When the distance between the two planets in conjunction in longitude falls short of the sum of their semi-diameters the lower planet covers partly or wholly the disc of the higher planet. The situation is analogous to the solar eclipse where the Moon eclipses the Sun. In such a case the lower planet is treated as the Moon and the upper one as the Sun, and all processes prescribed in the case of a solar eclipse are gone through in order to obtain the time of contact and separation, immersion and emersion, etc.

Vateśvara says :

"When the distance between the two planets (which are in conjunction) is less than half the sum of the diameters of the two planets, there is occultation *(bheda)* of one planet by the other. The eclipser is the lower planet. All calculations (pertaining to this occultation), such as those for the semi-duration etc. are to be made as in the case of a solar eclipse.

"When the Moon occults a planet, the time of conjunction should be reckoned from moon-rise and for that time one should calculate the *lambana* (parallax-difference in longitude) and the *avanati* (parallax-difference in latitude). In

case one planet occults another planet, the time of conjunction should be reckoned from the (occulted) planet's own rising and for that time one should calculate the *lambana* and the *avanati*."[104]

The whole process has been explained by Bhaṭṭotpala as follows :

"The planet which lies in she lower orbit is the occulting planet (or the occulter); it is to be assumed as the Moon. The planet which lies in the higher orbit is the occulted planet; it is to be assumed as the Sun. Then, assuming the time of conjunction (of the two planets) as reckoned from the rising of the occulted planet as the *tithyanta*, calculate the *lagna* for that *tithyanta*, with the help of (the longitude of) the occulted body, which has been assumed as the Sun, and the oblique ascensions of the signs. Subtracting three signs from that, calculate the corresponding declination (i.e. the declination of the *vitribha*).[105] Taking the sum of that (declination) and the local latitude when they are of like directions, or their difference when they are of unlike directions, calculate the *lambana* (for the time of conjunction) as in the case of a solar eclipse. When the longitude of the planets in conjunction is greater than (the longitude of) the *vitribha*, subtract this *lambana* from the time of conjunction; and when the longitude of the planets in conjunction is less than (the longitude of) the *vitribha*, add this *lambana* to the time of conjunction; and iterate this process: this is how the *lambana* is to be calculated. Then from the longitude of the *vitribhalagna* which has got iterated in the process of iteration of the *lambana*, severally subtract the ascending nodes of the two planets, and therefrom calculate the celestial latitudes of the two planets, as has been done in the case of the solar eclipse. Then taking the sum or difference of the declination of the *vitribhalagna*, the latitude of the *vitribhalagna*, and the local latitude, each in terms of degrees, (according as they are of like or unlike directions), in the case of both the planets. Then applying the rule: "Multiply the *R* sine of those degrees of the sum and difference by 13 and divide by 40: the result is the *avanati*," calculate the *avanatis* for the two planets. Then calculate the latitudes of the occulted and the occulting planets in the manner stated in the chapter on the rising and setting of the heavenly bodies, and increase or decrease them by the corresponding *avanatis* according as the two are of like or unlike directions: the results are the true latitudes (of the occulted and occulting planets). Take the sum or difference of those true latitudes according as they are of unlike or like directions. The result of this is the *sphuṭa-vikṣepa*.

Having thus obtained the *sphuṭa-vikṣepa*, one should see whether there exists eclipse-relation between this *sphuṭa-vikṣepa* and the diameters of the discs of the two planets. If the *sphuṭa-vikṣepa* is less than half the sum of the diameters of the two planets, this relation does exist; if greater, it does not. The totality of the occultation should also be investigated as before. Then, (severally) subtract the square of the *sphuṭa-vikṣepa* from the squares of the sum and the difference of the semi-diameters of the occulted and occulting planets, and take the square roots (of the results). Multiply them by 60 and divide by the difference or sum

of the daily motions of the planets as before: then are obtained the *sthityardha* and the *vimardārdha*, (respectively). They are fixed (by the process of iteration) as in the case of a solar eclipse. The *sthityardha* and *vimardārdha* having been obtained in this way, they should be corrected by the *lambana* obtained by the process of iteration. Then the time of apparent conjunction should be declared as the time of the middle of the occultation; this diminished and increased by the (*spārśika* and *maukṣika*) *sthityardhas*, (respectively), the times of contact and separation (of the two planets); and the same diminished and increased by the (*spārśika* and *maukṣika*) *vimardārdhas* (respectively), the times of immersion and emersion."[106]

Bhāskara II explains the same as follows :

"When there is *bheda-yuti*, then one should compute the *lambana* etc. as in the case of a solar eclipse. There, the lower of the two planets is to be assumed as the Moon and the upper one as the Sun. Why are they so assumed? To compute the *lambana* etc. But the *lagna*, which is obtained in order to find the *vitribhalagna*, is to be computed from the actual Sun, not from the assumed Sun. For what time is the *lagna* calculated from the Sun? For the time of conjunction (in longitude of the two planets). What is meant is this : On the day the conjunction (of the two planets) takes place, find the *ghaṭīs* of the night elapsed at the time of conjunction. Therefrom calculate the Sun as increased by six signs, and therefrom the *lagna*. Then calculate the *vitribha* and then the corresponding *śaṅku* (i.e. *R* sine of the altitude of the *vitribha*). Then, applying the rule: "Multiply the R sine of the difference of that *vitribha* and the assumed Sun by 4 and divide by the radius, and so on," calculate the *lambana* and *nati*, as before. Then correct the time of conjunction by that *lambana*. But the *lambana* etc. should be applied only when the two planets are fit for observation. In this *vheda-yuti*, the north-south distance between the planets is the latitude; and the direction of the latitude is that in which the assumed Moon lies, as seen from the assumed Sun. Now is stated the peculiarity in the case of *parilekha* (graphical representation of the occultation). When the lower planet, which has been assumed as the Moon, is slower or retrograde, then one should understand that the contact (of the two planets) occurs towards the east and the separation towards the west. In the contrary case, one should understand that the contact occurs towards the west and the separation towards the east. We have stated here the (notable) points of difference in the case of *Bheda-yoga:* there is no other difference in the procedure."[107]

Conjunction Along The Circle Of Position (Samaprotīma-Yuti)

Conjunction in longitude, though theoretically sound and perfect, suffered from one practical setback, viz. that there being no star at the pole of the ecliptic such a conjunction could not be observed with precision and so the calculated time of its occurrence could not be confirmed by observation. Brahmagupta noted that the stars

Citrā (Spica) and Svātī (Arcturus), which, though of unequal longitudes, were seen daily to be in conjunction along the circle of position *(samaprota-vṛtta)*. This conjunction was easily observable and agreement between computation and observation in this case could be established. Brahmagupta therefore gave preference to conjunction along the circle of position over conjunction in longitude.

To obtain the time when two planets are in conjunction along the circle of position, Brahmagupta first finds the time of their conjunction in longitude and then he derives how much earlier or later conjunction along the circle of position takes place. He states two rules for the purpose, one gross and the other approximate.

Brahmagupta's Gross Rule

Brahmagupta's gross rule runs as follows :

"Find the *udayalagna* (the rising point of the ecliptic at the time of rising of the planet) and also the *astalagna* (the setting point of the ecliptic at the time of setting of the planet) of the two planets equalized up to minutes of arc (i.e. for the time of their conjunction in longitude). Then find the *ghaṭīs* of the day-lengths of the two planets by adding together the times of rising at the local place of (1) the untraversed part of the *udayalagna,* (2) the traversed part of the *astalagna* as increased by six signs, and (3) the intervening signs, (in each case). If out of the two planets (in conjunction in longitude), the planet with lesser *udayalagna* is such that its *astalagna* increased by six signs is smaller than the other planet's *astalagna,* increased by six signs, one should understand that the conjunction of the two planets along the circle of position is to occur;[108] if greater, one should understand that the conjunction of the two planets along the circle of position has already occurred.

"Now (in the case of both the planets) multiply the minutes of the difference between the planet's *astalagna* plus six signs and the *udayalagna* by the *ghaṭīs* of the planet's own day-length. The result (in each case) should be taken as negative or positive according as the *astalagna* plus six signs is smaller or greater than the *udayalagna*. In case these results are both negative or both positive, divide the minutes of the difference between the planets' own *udayalagnas* by the difference of the two results; in case one result is positive and the other negative, divide the same minutes by the sum of the two results. (This gives the time, in terms of *ghaṭīs,* to elapse before or elapsed since the conjunction of the two planets along the circle of position, at the time of their conjunction in longitude). By these *ghaṭīs* multiply the minutes of the difference between the planet's *udayalagna* and *astalagna,* the latter increased by six signs, and divide by the *ghaṭīs* of the planet's own day-length. By the resulting minutes increase or diminish the planet's own *udayalagna* according as it is smaller or greater than the planet's (own) *astalagna* plus six signs: then is obtained the planets' common longitude at the time of their conjunction along the circle of position. In case it is less than the *udayalagna* for that time in the night or greater than the *udayalagna*

plus six signs, the two planets will be seen (in the sky) in conjunction along the circle of position."[109]

Śrīpati, following Brahmagupta, has stated this rule in his *Siddhānta-śekhara.*[110] But Lalla and Vaṭeśvara have omitted it.

Brahmagupta's Approximate Rule

The second rule of Brahmagupta which is intended to give better time of conjunction (of two planets along the circle of position) than the first rule (stated above), runs as follows :

"Multiply the duration of day for the planet with greater day-length by the time (in *ghaṭis*) elapsed (at the time of conjunction in longitude) since the rising of the planet with smaller day-length and divide by the duration of day for the planet with smaller day-length. When the resulting time is greater than the time elapsed (at the time of conjunction in longitude) since the rising of the planet with greater day-length, (it should be understood that) the conjunction of the two planets (along the circle of position) has already occurred; when less, (it should be understood that) the conjunction of the two planets (along the circle of position) is to occur.[111]

"The difference of the two times (in terms of *ghaṭis*) is the "first". A similar result derived from the two planets, diminished or increased by their motion corresponding to "arbitrarily chosen *ghaṭis*"[112] (as the case may be), is the "second". When the "first" and the "second" both correspond to conjunction past or to occur, divide the product (of the *ghaṭis*) of the "first" and the "arbitrarily chosen *ghaṭis*" by the *ghaṭis* of the difference between the "first" and the "second"; in the contrary case (i.e. when out of the "first" and the "second", one corresponds to conjunction past and the other to conjunction to occur), divide the product by (the *ghaṭis* of) the sum of the "first and the "second". The resulting *ghaṭis* give the *ghaṭis* elapsed since or to elapse before the conjunction along the circle of position, at the time of conjunction in longitude, depending upon whether the "first" relates to conjunction past or to occur.

"The conjunction of two planets, along the circle of position, takes place when the result (in *ghaṭis*) obtained on dividingby the *ghaṭis* of the day-length of one planet, the product of the *ghaṭis* elapsed since the rising of that planet and the *ghaṭis* of the day-length of the other planet, is equal to the *ghaṭis* elapsed since the rising of the other planet."[113]

This latter rule of Brahmagupta has been adopted by Lalla[114] and Śrīpati.[115]

Alternative Form Of Brahmagupta's Approximate Rule

Brahmagupta has stated his approximate rule in the following alternative form also ;

"Multiply the *nāḍis* of the duration of day for the planet with smaller day-length by the *ghaṭīs* elapsed since the rising of the planet with greater day-length and divide by the *ghaṭīs* of the duration of day for the planet with greater day-length: the result is in terms of *nāḍis*. When these *nāḍis* are less than the *ghaṭīs* elapsed since the rising of the planet with smaller day-length, (it should be understood that) conjunction (along the circle of position) of the two planets has already occurred; when greater, (it should be understood that) conjunction is to occur. Assume the difference of the two, in terms of *ghaṭīs*, as the "first". Now multiply the daily motion of each planet by "the arbitrarily chosen *ghaṭīs*" and divide each product by 60: add the result to or subtract it from the longitude of the corresponding planet according as the conjunction has occurred or is to occur. Then obtain the difference similar to the "first" and call it "second". When both the differences, the "first" and the "second", correspond either to conjunction past or to conjunction to occur, divide the product of the "first" and the "arbitrarily chosen *ghaṭīs*" by the difference of the "first" and the "second"; in the contrary case (i.e. when out of the "first" and the "second", one corresponds to conjunction past and the other to conjunction to occur), divide that product by the sum of the "first" and the "second". The resulting *ghaṭīs* give the *ghaṭīs* elapsed since or to elapse before the conjunction of the two planets (along the circle of position), depending upon whether the "first" relates to conjunction past or to conjunction to occur. If by applying the above rule once conjunction of the two planets is not arrived at, the rule should be iterated (until one does not get the conjunction of the two planets)."[116]

This alternative form of Brahmagupta's approximate rule has been adopted by Vaṭeśvara who states it as follows :

"Multiply the duration of day for the planet with smaller day-length by the time (in *ghaṭīs*) elapsed since the rising of the planet with greater day-length, and divide by the duration of day for the planet with greater day-length. When the resulting time is greater than the time elapsed since the rising of the planet with smaller day-length, (it should be understood that) the conjunction (along the circle of position) of the two planets is to occur; in the contrary case, (it should be understood that) the conjunction has already occurred.

"The difference of the two times (in terms of *ghaṭīs*) is the "first". A similar difference derived from the "*ghaṭīs* arbitrarily chosen" (for *ghaṭīs* elapsed since or to elapse before conjunction) is the "second". When both the "first" and the "second" correspond either to conjunction past or to conjunction to occur, divide the product of the "first" and the "arbitrarily chosen *ghaṭīs*" by the *ghaṭīs* of the difference between the "first" and the "second"; in the contrary case (i.e. when out of the "first" and the "second", one corresponds to conjunction past and the other to conjunction to occur), divide that product by (the *ghaṭīs* of) the sum of the "first" and the "second". The resulting *ghaṭīs* give the *ghaṭīs* elapsed since or to elapse before the conjunction of the two planets (along

the circle of position), depending on whether the "first" relates to conjunction past or to occur."[117]

Munīśvara has criticised conjunction along the circle of position advocated by Brahmagupta, for the reason that the time of such a conjunction will differ from place to place, and so it will create confusion in making astrological predictions. See *Siddhānta-sārvabhama, Bharahayuti*, vs. 15, p. 543.

Āryabhaṭa II's Rule

Āryabhaṭa II gives the following rule to find the time of conjunction in celestial longitude and that of conjunction along the circle of position :

"Divide the difference (in minutes) between the longitudes of the two planets (whose conjunction is under consideration) by the difference between the daily motions (of the two planets), provided they are both direct or both retrograde; if one of the planets is retrograde (and the other direct), divide by the sum of the daily motions (of the two planets); the result gives the days elapsed since the conjunction of the two planets, in case the faster planet is greater than the other, and also if the planet with lesser longitude is retrograde (and the other direct). When both the planets are retrograde, the case is contrary to what happens when both the planets are direct. The two planets should then be calculated for the time of conjunction. Then the two planets become equal in longitude.

When conjunction suitable for observation (i.e. along the circle of position) is required, then the two planets should be corrected for the *ayana-dṛkkarma* and *akṣa-dṛkkarma* also. The time when they become equal in longitude, is certainly the time of conjunction (along the circle of position)."[118]

Indications of this rule occur in the *Sūrya-siddhānta*[119] and the *Vaṭeśvara-siddhānta*[120] also. According to Kamalākara, a staunch follower of the *Sūrya-siddhānta*, however, the conjunction of the planets and stars taught in the *Sūrya-siddhānta* is in celestial longitude.[121]

Conjunction In Polar Longitude (Dhruvaprotīya-Yuti)

Bhāskara II has given rules for conjunction in celestial longitude as well as conjunction in polar longitude. But as there is no star at the pole of the ecliptic conjunction in celestial longitude does not, says he, create confidence in the observer; while there being one at the pole of the equator conjunction in polar longitude better for observation. However, conjunction of two planets, in his opinion, really occurs when the two planets are nearest to each other and this happens when the two planets are in conjunction in celestial longitude only.[122] He has given no credit

to conjunction along the circle of position probably because it was not universal. He has not even mentioned this conjunction.

Bhāskara II's rule for the conjunction of two planets in polar longitude rus thus :

"Divide the minutes of the difference between the longitudes of the two planets by the difference of their daily motions (if both planets are direct or both retrograde); if one of them is retrograde (and the other direct), divide by the sum of the daily motions (of the planets): the result is the number of days elapsed since the conjunction of the two planets provided the slower planet has lesser longitude than the other, or if, one planet being retrograde, its longitude is lesser than that of the other. If otherwise, the conjunction occurs after the days obtained. If both the planets are retrograde, the result is contrary to that for direct planets. (This gives approximate time for conjunction. To get accurate time, proceed as follows :)

"(Calculate the longitudes of the planets for the time of conjunction and) apply the *ayana-dṛkkarma* (to them). Iterate the process until the time of conjunction is not fixed. When this is done, the two planets lie on the same great circle passing through the poles of the equator. The planets are then said to be in conjunction in the sky. If the *ayana-dṛkkarma* is not applied, the planets lie on the same secondary to the ecliptic."[123]

2. CONJUNCTION OF A PLANET AND A STAR

The conjunction of a planet and a star is treated in the same way as the conjunction of two planets and the rules in the two cases are similar. The only remarkable difference is that the stars, unlike the planets, are supposed to be points of light having no diameter and fixed in position having no eastward daily motion.

Bhāskara I says :

"All planets whose longitudes are equal to the longitude of the junction-star of a *nakṣatra*[124] are seen in conjunction with that star. (Of a planet and a star) whose longitudes are unequal, the time of conjunction is determined by proportion."[125]

"The distance between a planet and a star (when they are in conjunction) is determined from (the sum or difference of) their latitudes.[126]

Brahmagupta says :

"If the longitude of a planet is less than the longitude *(dhruvaka)* of a star, their conjunction is to occur; if greater, their conjunction has already occurred. If the planet is retrograde, reverse is the case. The rest is similar to that stated in the case of the conjunction of two planets.[127]

Lalla says:

"If the longitude of a planet is greater than the longitude of the junction-star of a *nakṣatra,* their conjunction has already taken place; if less, it will take place. If the planet is retrograde, the contrary is the case. The rest is similar to that in the case of the conjunction of two planets."[128]

A similar statement has also been made by Vaṭeśvara,[129] Āryabhaṭa II,[130] Śrīpati,[131] the author of the *Sūrya-siddhānta,*[132] and others.

In the case of occultation, Brahmagupta says :

"When a planet is on the same side of the ecliptic as the junction star of a *nakṣatra,* the planet will occult the junction star if its true latitude is greater than the latitude of the junction star minus the semi-diameter of the planet or less than the latitude of the junction star plus the semi-diameter of the planet.[133]

The occultation of a star by the Moon was considered important. So the occultation of certain prominent stars was specially noted and recorded by the Indian astronomers.

Bhāskara I says :

"The Moon, moving towards the south of the ecliptic, destroys (i.e. occults) the Cart of Rohiṇī (the constellation of Hyades), when its latitude amounts to 60 minutes; the junction star of Rohiṇī (i.e. Aldebaran), when its latitude amounts to 256 minutes; (the junction star of) Citra (i.e. Spica), when its latitude amounts to 95 minutes; (the junction star of) Jyeṣṭhā (i.e. Antares), when its latitude amounts to 200 minutes; (the junction star of) Anurādha,[134] when its latitude amounts to 150 minutes; (the junction star of) Śatabhiṣak (i.e., λ Aquarii), when its latitude amounts to 24 minutes; (the junction star of) Viśakha,[135] when its latitude amounts to 88 minutes; and (the junction star of) Revatī (i.e., Zeta Piscium), when its latitude vanishes. When it moves towards the north (of the ecliptic), it occults the *nakṣatra* Kṛttikā (i.e. Pleiades), when its latitude amounts to 160 minutes; and the central star of the *nakṣatra* Maghā, when it assumes the greatest northern latitude. These minutes (of the Moon's latitude)..are based on actual observation made by means of the Yaṣṭi instrument (i.e. the Indian telescope)."[136]

Brahmagupta says :

"The planet whose south latitude at 17° of Taurus exceeds 2°, occults the Cart of Rohiṇī.[137] The Moon, when it has the maximum north latitude, occults the third star of Maghā; when it has no latitude, it occults Puṣya, Revatī and Śatabhiṣak."[138]

Lalla says :

"The Moon, situated in the middle of the *nakṣatra* Rohiṇī, occults the Cart of Rohiṇī, when its southern latitude amounts to 2°40′; (the junction star of) the *nakṣatra* Rohiṇī, when its southern latitude is 4°30′; the middle of the *nakṣatra* Maghā, when its north latitude amounts to 40°30′; and the *nakṣatras* Revatī, Puṣya and Śatabhiṣak, when is devoid of latitude."[139]

Vateśvara says :

"The planet, whose latitude at 17° of Taurus amounts to 1½ degrees south, occults the Cart of Rohiṇī. The Moon with its (maximum) latitude south (i.e., 4°30′ S) covers the junction star of Rohiṇī."[140]

Śrīpati similarly says :

"The planet whose southern latitude at 17° of Taurus exceeds 2° certainly occults the Cart of Rohiṇī. The Moon with its longitude equal to that of (the junction star of) Maghā occults the third star of Maghā, when it has maximum (north) latitude; and the *nakṣatras* Śatabhiṣak, Revatī and Puṣya when its longitude is equal to their longitudes."[141]

9

INDIAN CALENDAR FROM POST-VEDIC PERIOD TO AD 1900

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Calendar is really a method for counting in a systematic and continuou s manner the successive days in the ever-flowing aeon of time by cyclic periods in unit s named as year, which for the sake of convenience is normally divided into 12 parts known as months, for the purpose of recording in a chronological and systematic manner past and current events and for fixing and communicating precisely the time whe n future activities are proposed to be undertaken. The basis of calendar keeping has been the motion of two luminaries in the sky, namely the Sun and the Moon. The time period of the successive return of the Sun to the same star or equinox, which is really the time period of the revolution of the Earth around the Sun, forms the measure of the solar year and is the basis of all solar calendars. Again the time period of the successive return of the Moon in opposition or conjunction to the Sun in the relation to Earth, when full moon or new moon occurs, is the measure of the lunar month and 12 such successive months form the lunar year, and this is the basis of all lunar calendars. In the present day also the above two types of calendars are in use.

In the earliest recorded period of Indian history, which is the Vedic period, there is evidence of some calendric system based on the motion of the Sun and the Moon being followed then, but the development of calendric astronomy in India in a systematic manner may be taken to have commenced from the time when the first treatise known as *Vedāṅga Jyotiṣa* containing elementary astronomical data regarding the Sun and the Moon for calendar keeping was compiled.

VEDĀṄGA JYOTIṢA

There is no clear indication whent he *Vedāṅga Jyotiṣa* text was written or when it came into use. It can only be inferred from the astronomical references given in the text. In the Yajus as well as the ṚK recension of the *Vedāṅga Jyotiṣa* it has been mentioned that the *yuga,* which is the five-year cyclic period of this calendar, commences from the *śukla-pratipada* day of the month of Māgha when the Sun and the Moon return together at Śraviṣṭhā *nakṣatra,* (which was later called Dhaniṣṭhā and identified now as β Delphini), and when also *uttarāyaṇa* (winter solstice) takes place. It, therefore, points to the astronomical situation that at the time when the *Vedāṅga Jyotiṣa* text was written, the winter solstitial point was on the latitude great circle psssing through ecliptic pole and Dhanṣṭhā star which may be presumed to be either β or α Delphini, and this gives the approximate time of formulating the *Vedāṅga Jyotiṣa*

somewhere between 1400 and 1300 B.C. It can not be said with certainty that visual observation made at the time was very accurate, and Colebrooke suggested that the 1100 B.C. would be more reasonable.

The *Vedāṅga Jyotiṣa* is available in two recensions, the Ṛk and the Yajus. There is also another book known as *Atharva Jyotiṣa* but it is quite a different one. The *Vedāṅga Jyotiṣa* attached to the Ṛgveda has 36 verses and is ascribed to one Lagadha of whom nothing much is known. The *Jyotiṣa* attached to the Yajurveda has 44 verses.[1] There is much in common between the two books. Out of 36 verses of Ṛk recension 30 are found in the Yajus recension, and the total verses dealing with the *Vedāṅga Jyotiṣa* become 50.[2] The verses, however, do not seem to be arranged in a very systematic manner, and this tends to indicate the possibility of some meddling with the original text.[3]

The *Vedāṅga Jyotiṣa* calendar was formulated on the basis of cycle-periods of 5 years, which have been called *yuga* with the stipulation that at the commencement of each yuga period both the Sun and the Moon would be at the Dhaniṣṭhā *nakṣatra*, when it would also be the *uttarāyaṇa* day. The details of this *yuga* period as ascertained from Vedāṅga Jyotiṣa are given below :

(1)	Number of years	5
(2)	Number of *sāvana* or civil days (5×366 days)	1830
(3)	Number of solar months (5×12)	60
(4)	Number of lunar months (synodic) ($1830 \div 29.53$)	62
(5)	Number of lunar months (sidereal) ($1830 \div 27.32$)	67
(6)	Number of intercalary lunar months (62—60)	2
(7)	*Tithis* (lunar days) (62×30 days)	1860
(8)	Number of omitted or *kṣaya tithis* (1860—1830)	30
(9)	Number of *nakṣatra* days (67×27 days)	1809

Let us examine how the above calendar satisfied the three main astronomical stipulations made in the text, namely, (a) at the beginning of each yuga, when the year started from the 1st day of the month of Māgha, the Sun and the Moon returned together: this is the same thing as saying that it was a new-moon day, same as the beginning of *śukla pratipada* day; (b) at that time the Sun in conjunction with the Moon was at the Dhaniṣṭhā *nakṣatra* (β Delphini), meaning that the Sun was located on the latitude great circle passing through Dhaniṣṭhā star; and (c) the first day of the *yuga* cycle coincided with the *uttarāyaṇa* day, that is, the Sun was also then at the winter solstitial point, that is, on that day the solstitial colure passed through Dhaniṣṭhā star.

Analyzing the first stipulation, it will be observed that 62 synodic lunar months equal 62×29.53059 days $=$ 1830.8965 days, say 1830.9 days. But the length of a *yuga* comprises of 1830 days, and hence to maintain the arrangement that the first day of the *yuga* will be a new-moon day, same as the beginning of *śukla pratipada*, it is necessary to add one day of the five-year period of *yuga* of 1830 days. It is very likely

that this day was added at the end of the *yuga* period.[4] But this correction will exceed by 0.1 day after each *yuga* period, and hence to keep the adjustment correct, the addition of one day is to be omitted after some *yugas*. This was also very probably done on the basis of observation.

Regarding the second stipulation that the *yuga* began with the Sun and the Moon returning together at the Dhaniṣṭhā *nakṣatra* it should be stated that this could not possibly happen for all *yugas*. It was perhaps the case when the *Vedāṅga Jyotiṣa* calendar was first introduced, and similar conditions could only be obtained at intervals of several *yugas* after applying corrections as explained below. As the *yugas* commenced with the Sun returning to the star Dhaniṣṭhā, the year was sidereal. Hence the correct length of 5 solar years of the *yuga* will be equal to $5 \times 365.25635 = 1826.2817$ days. The length of 62 synodic lunar months is equal to $62 \times 29.53059 = 1830.8965$ days. The difference between the two is 4.6148 days, and this means that the new moon will occur later successively by the above period in each *yuga* in relation to the Sun returning to Dhaniṣṭhā *nakṣatra*, and this difference will increase to one lunar month in 6.4 *yugas*. It is obvious that this incongruity in the occurrence of the phases of the Moon in relation to the calendar days could not have escaped the notice of the *Vedāṅga Jyotiṣa* astronomers who must have carried out the required adjustments to prevent the calendar from going astray for the laid down stipulations otherwise it could not have continued to be in use for as long a period as more than 1000 years.

The correction to be required will be the omission of three lunar months in 19 *yugas*, which means omission of one lunar month after each of the two successive 6-*yuga* periods, and then one lunar month again after the 7-*yuga* period. This might have been done by having one intercalary month instead of two at the end of the *yugas* mentioned above.[5] Perhaps the necessary adjustments were carried out by the assembly of priests responsible for the calendar on an ad-hoc basis as and when it was found necessary on actual observations, or on some formula as mentioned above, the actual mode adopted being as, however, not known.

As regards, the third stipulation that the 1st day of the *yuga* will be the *uttarāyaṇa* day with the Sun and the Moon returning to Dhaniṣṭhā *nakṣatra*, it should be said that this astronomical situation could not have continued for a very long time. This is because the length of sidereal year and tropical year is not the same, the latter is shorter than the former by $20^m\ 24^s$ due to the precessional motion of the Earth which is at present $50''.27$ per year, and was about $49''.61$ at 1000 B.C. and it was $49''.83$ in the beginning of the Christian era. It took approximately 72.6 years at that time for the winter solstitial point to move by $1°$, and hence in the course of about 970 years this point would retrograde through one *nakṣatra* division. This precessional motion was not known to the *Vedāṅga Jyotiṣa* astronomers, and as a matter of fact in that early age it was also not known to astronomers of other ancient nations. As the precessional motion is very slow, the marked shifting of the winter solstitial colure from the latitude great circle passing through Dhaniṣṭhā would have been markedly observed only after a large number of *yugas*, rather after a few centuries, and nothing

seems to have been done because nothing could be easily done unless the stipulation that the year starts from Dhaniṣṭhā *nakṣatra* was changed. It was only at about 400 B.C. or so, when the winter solstitial point had retrograded by one *nakṣatra* division from Dhaniṣṭhā to Śravaṇa, certain adjustments were effected by the then astronomers to conform to the changed astronomical situation as may be seen from the verse 44.2 in *Aśvamedha Parva* of the *Mahābhārata* where it is stated that the *nakṣatras* start from Śravaṇa, and the seasons from Śiśira (winter) and the month from *śukla pratipada*. This really means that the year-beginning was changed from Dhaniṣṭhā to Śravaṇa *nakṣatra* in order to keep the months of the calendar, counted from the first one, adjusted to the seasons as before.

It has been mentioned that a *yuga* comprises of 62 lunar months of which two are intercalary, and these were placed after every 30 lunar months. As the year started with Māgha, in the 3rd year there were two lunar Srāvaṇas, the first one being an intercalary or *adhika* month. Similarly in the 5th or last year of a *yuga*, an intercalary or *adhika* month was placed at the end—this being an *adhika* Māgha, it was added at the end of the year.[6] It might possibly have been named as Pauṣa even though it was coming after the normal Pauṣa because Māgha being the 1st month of the year, a *mala* month named as Māgha occurring at the end of the year might have been avoided.

One of the important objectives of the *Vedāṅga Jyotiṣa* calendar was the correct prediction of *tithi* and *nakṣatra* day for any *sāvana* (civil) day, and the rules in this matter gave more accurate results. A *tithi* in this calendar has been defined as 1/30th part of a lunar month, there being 1860 *tithis* in a *yuga* of 1830 civil days or 62 *tithis* in the period of 61 days. So to keep the relation between the *tithi* day and civil day correct in the cycle of *yugas*, one *tithi* was omitted after 61 civil days, that is, then a *kṣaya tithi* occurred. The months of the *Vedāṅga Jyotiṣa* calendar were lunar, and hence its length in the number of civil days was governed by the above factor. The correct mean length of a *tithi*, however, is equal to $\frac{29.53059}{30}$ civil day $= 0.984353$ day, and so 62 *tithis* will actually measure 62×0.984353 days $= 61.029886$ days. This excess period would work out as 1 day in about 2075 days or in about 5.67 years. Therefore to keep correct the *tithi* calculations, one day was added at the end of a *yuga* as it was found necessary. (See also note at the end of the Table 9.1).

During the *Vedāṅga Jyotiṣa* times, the days were also reckoned by the name of *nakṣatras*, that is, by the *nakṣatra* divisions which the Moon then occupied. The number of *nakṣatara* days in a *yuga* of 1830 civil days was 1809, and hence the difference between the civil days and *nakṣatra* days in a *yuga* was 21. This means that 86.143 *nakṣatra* days are equivalent to 87.143 civil days. The relation between the two forms of days was maintained by counting successively one *nakṣatra* day for each civil day for 86 days and then repeating the same *nakṣatra* day on the 87th day so that 86 *nakṣatras* were spread over 87 days. However, the correct length of 1 *nakṣatra* day $= 27.32166$ or 1.011913 days, while the length actually taken is $\frac{1830}{1809}$ or 1.011608

days. The difference is 0.000305 days on the less side, and hence a further correction of 1 *nakṣatra* day after 3279 days or about 9 years would be required to keep the calendar correct, and this was probably done as and when required.

The five different years of the *yuga* have different names, which are (1) Samvatsara, (2) Parivatsara, (3) Idāvatsara, (4) Anuvatsara, and (5) Idvatsara. These names, incidentally, are not found in the *Vedāṅga Jyotiṣa* text as known to us, but commentator Somākara has quoted some verses belonging to Garga which describes the five-year *yuga* as that given in the *Vedāṅga Jyotiṣa* text, and mentions the names of the five years as mentioned above. The worked-out layout of the five-year *yuga* in terms of its months and their lengths is shown in Table 9.1 below:[7]

Table 9.1

Months	Name of the years				
	Sam-vatsara	Pari-vatsara	Idā vatsara	Anu-vatsara	Id-vatsara
	1	2	3	4	5
Māgha	30	29	29	29	29
Phālguna	30	30	30	30	30
Caitra	29	29	29	29	29
Vaiśākha	30	30	30	30	30
Jyaiṣṭha	29	29	29	29	29
Aṣāḍha	30	30	30	30	30
Śrāvaṇa (Adhika)	—	—	—	—	—
Śrāvaṇa	29	29	29	29	29
Bhādrapadā	30	30	30	30	30
Āśvina	29	29	29	29	29
Kārtika	30	30	30	30	30
Mārgaśīrṣa	29	29	29	29	29
Pauṣa	30	30	30	30	30
Pauṣa or Māgha[8] (Adhika)	—	—	—	—	29 or 30
Total No. of the days of each of the year	355	354	384	354	383 or 384
Total no. of days in a yuga........................1830 or 1831 days					

The *Vedāṅga Jyotiṣa* book has given the list of 27 *nakṣatras* at two different places,[9] and at one place the deities of the *nakṣatras* are also mentioned. Incidentally the

nakṣatra system was known also in the Vedic period. Though *Ṛk Saṃhitā* does not mention names of all the 27 *nakṣatras* in the Moon's path, the *Taittirīya Brāhmaṇa* gives the names of all the 27 *nakṣatras* with deities, and *Atharva Saṃhitā* mentions 28 *nakṣatras*—Abhijit being the additional one.

It will be noticed that *Vedāṅga Jyotiṣa* months are *amānta,* that is, these ended with *amāvasyā* and began with *śukla pratipada* while in Vedic times the months were generally (*pūrṇimānta,* that is, those ended with *pūrṇimā* and began with *kṛṣṇa pratipada.* But there were variations from this pattern. In *Sūryaprajñapti,* it is mentioned that the year started from full-moon day occurring at Abhijit *nakṣatra.* As it happens, both these systems are still followed in the country, the north and north-west parts mostly follow *pūrṇimānta* system while other parts follow *amānta* system, but in determining lunar months and also for fixing the *adhika* and *kṣaya* months, *amānta* system is followed.

In the *Vedāṅga Jyotiṣa* the first *nakṣatra* is not specifically mentioned. It has, however, been stated that the year starts with the Sun at Dhaniṣṭhā *nakṣatra,* but while mentioning the lords of the *nakṣatras* in verses 38 to 40 of *Yajur Jyotiṣa,* the list starts with Kṛttikā. This, it appears, is the consequence of the practice followed in early Vedic times when spring equinox was located at that group of stars, and the year started from that *nakṣatra.* The *rāśi* system for indicating the positions of the Sun and the Moon on the basis 12 equal divisions of the ecliptic was not in use, their positions being given with respect to *nakṣatras.*

The *Vedāṅga Jyotiṣa* calendar has been framed on the basis of the mean motions of the Sun and the Moon, and there is no reference about the motion of the planets. The true motions of these two luminaries were not used because it required constant and careful observations, and astronomy had not developed then to that extent.

JAINA ASTRONOMICAL TREATISE—SURYAPRAJNAPTI

Several other treatises dealing with calendar can be assigned to the later part of the *Vedāṅga Jyotiṣa* period, and the main book of this period dealing with astronomy as propounded by the Jaina sect, is *Sūryaprajñapti.* The authorship of this book is assigned to Lord Mahāvīra who lived at about 500 B.C. but it is likely that the book was composed at a later date at about 200 B.C. or so.[10] A well known commentary of this treatise is by Malayagiri.

For calendrical purposes *Sūryaprajñapti* adopted the same 5-year *yuga* system of *Vedāṅga Jyotiṣa* calendar but started the *yuga* cycle from summer solstice with the full-moon taking place at Abhijit *nakṣatra.* This indicates that full-moon ending month was followed as opposed to the new-moon ending month of the *Vedāṅga Jyotiṣa.* The zodiac was divided into 28 *nakṣatra* divisions instead of 27, and these were not all equal, and the *nakṣatras* commenced from Abhijit.[11]

TRANSITION PERIOD FROM *VEDĀNGA JYOTISA* TO *SIDDHĀNTA JYOTISA*

The indigenous *Vedāṅga Jyotiṣa* calendric system exerted its influence for a very long time, its use having continued till the time of Satavāhana rulers (200 A.D.). Its hold started dwindling when improved astronomical knowledge gave rise to a more scientific and accurate method of predicting astronomical events and consequently to a more correct system of calendar keeping. This astronomical knowledge was called 'Siddhānta Jyotiṣa', and it gradually superseded the old *Vedāṅga Jyotiṣa*, and by about 400 A.D. it completely replaced the old Vedāṅga system. This transition period extended approximately from A.D. 100 to A.D. 400, and is often termed as a 'dark' period of Indian astronomy because during this period no record of its advancement or of compilation of any book by any reputed astronomer is found. But looking from the point of view of development of Indian astronomy, it may not be appropriate to call it so.

The invasion of India by Alexander in 326 B.C. and successive invisions during 300 B.C. to A.D. 200 by the Macedoninan and Bactrian Greeks (Yavanas), Śakas, Parthians (Pahlavas), and Kuṣāṇas some of whom afterwards settled down in this country along with their scholars learned in science, art, and culture and made India their home, opened up the processes of exchange of knowledge between Indian and foreign savants. The knowledge gained in the field of astronomy was mainly Graeco-Chaldean, and this influenced to a considerable extent our thinking on this discipline of science, and helped in evolving an improved and more scientific system of astronomy which came to be known as siddhāntic astronomy.

The knowledge obtained through the process of contacts with foreign astronomers did no doubt influence the evolution of siddhānta astronomy and the calendar based on it which is still in force, but it should be stressed that the Indian astronomers did not blindly accept and incorporate all the information obtained by them from non-indigenous sources in their new system. They studied and assimilated what is to be learnt from foreign sources, and blended this knowledge with their own after making careful observations and deliberations, and evolved a new system of astronomy in this country, the most prominent one being that which is enunciated in the *Sūrya Siddhānta*.

It should be appreciated that in these days acquisition and dissemination of knowledge was not an easy task. It must have been a very slow, time-consuming, and difficult process. To replace the well established *Vedāṅga Jyotiṣa* calendric system which has dominated the Indian scene for almost one and half millenium by a new system though more scientific but somewhat revolutionary, required a lot of deliberations not only between the leading Indian astronomers themselves, but also perhaps between the local and foreign astronomers, between the astronomers and the people in general as well as with the ruling elite. It would, therefore, not be unreasonable to think that this process took as long as nearly 300 years from A.D. 100 to A.D. 400 or so. Hence the so called dark period may be considered the time when vigorous

discussions between astronomers and the elite were going on, and gradual transition was taking place from Vedāṅga to Siddhānta system.

SIDDHANTIC ASTRONOMY : SURYA SIDDHANTA

The name *siddhānta* has by derivation the meaning "established conclusion." But in reality the name Siddhānta Jyotiṣa means scientific astronomy giving accurate conclusions. This system was no doubt a great advancement over the previous system or systems and carried a high esteem in the minds of the people. This led nearly all astronomers who compiled their treatises on the waning of the influence of the *Vedāṅga Jyotiṣa,* to suffix or prefix the word 'siddhānta' with the name of their book.

Though a number of books did appear under the title 'siddhānta', the most prominent book on siddhāntic astronomy which ultimately replaced the *Vedāṅga Jyotiṣa* system and which is still held in great veneration by *pañcāṅga* makers is *Sūrya Siddhānta.* It is not known who is the original author of this book or who compiled it first. The original treatise is not available. The first glimpses of this book is found in the *Pañca-siddhāntikā* of Varāhamihira (A.D. 550) who, it appears, redacted the version that he found in his time by improving some of the old constants taken mostly from Āryabhaṭa I, (A.D. 499). The second redaction took place after the time of Brahmagupta on the basis of his books *Brāhmasphuṭa siddhānta,* and *Uttara Khaṇḍakhādyaka.* But again, though much later, the then astronomers felt that the constants provided were no longer correct and needed improvement. A further change was made to some of the constants by improving on the number of revolutions that the luminaries were assumed to make in a Mahāyuga, and this correction is known as *bija* correction. These changes might have been effected from time to time, and according to Bentley the *bija* corrections, as followed now, came into use in the 16th century.[12]

The *Sūrya-siddhānta,* both Varāha's version and the modern, and other ancient books on Indian astronomy have all expressed the astronomical constants in terms of Mahāyuga consisting of 4.32×10^6 solar years following the lines of Āryabhaṭa I, and the Table 9.2 gives the number of civil days in a Mahāyuga as stated by different authorities, and the derived number of civil days in a solar year.[13]

Table 9.2. *Number of days in a Mahnyuga and a year*

Name of the book	*Days in a Mahāyuga*	*Days in a year*
Āryabhaṭīya of Āryabhaṭa	1577 917 500	365.258 680
Khaṇḍakhādyaka of Brahmagupta	1577 917 800	365.258 750
Sūrya-siddhānta of Varāhamihira	1577 917 800	365.258 750
Sūrya-siddhānta (Modern)	1577 917 828	365.258 756

The length of the solar year of the *Sūrya-siddhānta* has been compared with the modern value as well as that given by the Greek astronomers Ptolemy and Hipparchus, and this is shown below in Table 9.3. Hipparchus's value as used by

Romaka-siddhānta. *Sūrya-siddhānta* astronomers however did not use the length of the sidereal year as given by Ptolemy, which incidentally was more accurate, but calculated their own values.

Table 9.3. *Length of the Solar year*

	d	h	m	s	=	days
1. Varāhamihira's *Sūrya-siddhānta*	365	6	12	36.0	=	365.258 750
2. Modern or Current *Sūrya-siddhānta*	365	6	12	36.6	=	365.258 756
3. Correct modern value :[14]						
(a) *Sidereal year*						
(i) in mean solar days	365	6	9	8.5	=	365.256 349
(ii) in ephemeris days	365	6	9	9.7	=	365.256 363
(b) *Tropical year*						
(i) in mean solar days	365	5	48	44.4	=	365.242 188
(ii) in ephemeris days	365	5	48	45.6	=	365.242 194
4. Claudius Ptolemy	365	6	9	48.6	=	365.256 813[15]
5. Hipparchus (140 B.C.)	365	5	55	12.0	=	365.246 667[16]

A reference has already been made to the *bija* corrections made to some of the constants of *Sūrya-siddhānta,* and Table 9.4 below shows the constants of planetary revolutions given in the *Sūrya-siddhānta* before and after *Bija* corrections.

Table 9.4. *Planetary revolutions (sidereal) in one Mahāyuga of* 4.32 × 10⁶ *years assumed at different stages of redaction of Sūrya-siddhānta*[17]

Sun, Moon and the planets	*Sūrya-siddhānta* of Varaha-mihira	Modern *Sūrya-siddhānta*	Change made in modern *siddhānta* (Cols 2 & 3)	Revolutions in modern *Sūrya-siddhānta* revised by *bija* correction	Change made from modern *Sūrya-siddhānta* by *bija* correction (Cols 3 & 4)
1	2	3	4	5	6
Sun	4 320 000	4 320 000	Nil	4 320 000	Nil
Moon	57 753 336	57 753 336	Nil	57 753 336	Nil
Moon's apogee	448 219	448 203	—16	448 199	— 4
Moon's node	232 226	232 238	+12	232 242	+ 4
Mercury	17 937 000	17 937 060	+60	17 937 004	—16
Venus	7 022 388	7 022 376	—12	7 022 364	—12
Mars	2 296 824	2 296 832	+ 8	2 296 832	Nil
Jupiter	364 220	364 220	Nil	364 212	— 8
Saturn	146 564	146 568	+ 4	146 580	+12

On the basis of the number of *sāvana* (civil) days and of the number of the revolutions that the Sun, Moon, and planets make in a Mahāyuga, another Table numbered 9.5 has been placed below which shows the sidereal period in days of one revolution by the Sun, the Moon and planets as adopted at different stages of development of *Sūrya-siddhānta.*[18]

Table 9.5. *Period in days of one sidereal revolution of the Sun, the Moon, and the Planets*

Planets	*Sūrya-siddhānta* (Varāha-mihira)	*Sūrya-siddhānta* (in modern)	*Sūrya-siddhānta* (in modern) with *bīja* correction	Sidereal period (modern correct value)
1	2	3	4	5
Sun	365.258750	365.258756	No change	265.25636
Moon	27.32167	27.32167	No change	27.32166
Moon's apogee	3231.98768	3232.09367	3232.12015	3232.58853
Moon's nodes	6794.75080	6794.39983	6794.28280	6793.45994
Mercury	87.969995	87.96970	87.96978	87.96926
Venus	224.69818	224.69857	224.69895	224.70080
Mars	686.99987	686.997493	No change	686.97985
Jupiter	4332.32057	4332.32065	4332.41581	4332.58892
Saturn	10766.0667	10765.77307	10764.89171	10759.22653

A third Table (9.6) below shows the period in days of one synodic revolution of the Moon and the planets with *bīja* corrections where applicable along with the modern value.

Table 9.6. *Period in days of one synodic revolution of the Moon and the planets*

Planets	Period derived from the *Sūrya-siddhānta* (modern)	Modern correct value
Moon	29.530588	29.530588
Moon's apogee	411.79535[19]	411.78470
Moon's nodes	346.62433[19]	346.62003
Mercury	115.87815[19]	115.87748
Venus	583.90277[19]	583.92137
Mars	779.92427	779.93610
Jupiter	398.88837[19]	398.88405
Saturn	378.08747[19]	378.09190

CORRECTIONS FOR THE INEQUALITIES IN THE MOTION OF THE MOON

It will be seen that *Sūrya-siddhānta* astronomers were more accurate in calculating the synodic periods of the planets than the sidereal periods. In the case of the Moon they were marvellously successful in determining the correct value of the lunar month, but in calculating its daily position they were not so accurate. In calendar-making the Moon and the Sun play the main role. To calculate precisely the true position of the Moon a number of corrections, which are nearly as many as 1500, are required to be applied to its mean position. The three foremost causes for the inequality in the motion of the Moon are (a) equation of centre:—inequality of its motion due to its elliptical path around the earth causes a difference in angle between the true Moon and the mean Moon to the maximum extent of about 6°17′; (b) evection:—inequality of motion due to variation of the eccentricity of the elliptical orbit of the Moon causing a variation of the 'equation of the centre', and this causes a further difference which can amount to about 1°16'; (c) variation:—inequality in the motion of the Moon due to the magnitude of variation of attraction of the Sun on the earth-moon system during a synodic month, that is, when the Moon is nearest to the Sun during conjunction the latter's attraction is more on the former than when the Moon is farthest away during opposition, and this causes a difference to the extent of about 39′. There is also another cause for producing a small inequality in the Moon's motion known as (d) Annual Equation. This is due to annual variation of the earth's distance from the Sun, which is greatest at aphelion, and least at perihelion. The maximum value on this account may be up to about 11′ of arc.

The four principal terms for calculating the modern value of the inequalities of the Moon's motion for all the four causes mentioned in the preceding paragraph are given below:—[20]

(a)	Equation of centre	.. 377′.3	Sin g
(b)	Evection	.. 76′.4	Sin $(2D—g)$
(c)	Variation	.. 39′.5	Sin $2D$
(d)	Annual Equation	.. — 11′.2	Sin g'

Where g and g' are respectively the angular distances of the mean Moon and the mean Sun from their respective perigees (mean anomalies of the Moon and the Sun), and D represents the angle between the mean Moon and the mean Sun.

The early Indian astronomers measured anomaly from apogee as against the modern system of measuring it from perigee, and if g^1 represents this angle from apogee, then g^1 will equal $g+180°$. In this case, the three terms catering for the first three inequalities mentioned in the preceding paragraph which cause the greatest

difference between the true and the mean positions of the Moon, namely (a) equation of centre, (b) evection, and (c) variation, can be rewritten by using g_1 as follows :—

(a)	Equation of centre	.. $-377'.3 \operatorname{Sin} g_1$
(b)	Evection	.. $+76'.4 \operatorname{Sin} g_1 - 152'.8 \operatorname{Cos} (D-g_1) \operatorname{Sin} D$
(c)	Variation	.. $+ 39'.5 \operatorname{Sin} 2D$

By adding the above four terms, the expression for calculating the three inequalities takes the form in three terms as below :—

$$-300'.9 \operatorname{Sin} g_1 - 152'.8 \operatorname{Cos} (D-g_1) \operatorname{Sin} D + 39'.5 \operatorname{Sin} 2D$$

The earlier Indian astronomical treatises took into account the inequality of the Moon's motion by using expressions which were nearly the same as the first term of the above expression as shown below :

(a)	*Āryabhaṭīya* (also *Sūrya-siddhānta*)	.. $300'.25 \operatorname{Sin} g_1$
(b)	*Khaṇḍakhādyaka*	.. $296' \operatorname{Sin} g_1$
(c)	*Brāhma-sphuṭa-siddhānta*	.. $293.5 \operatorname{Sin} g_1$

The inequality covered by the second term of the above expression was dealt by Muñjāla (A.D. 932), and this was given by him in the form

$$-144' \operatorname{Cos} (S_L - a) \operatorname{Sin} D$$

Where S_L stands for longitude of the mean Sun, and a stands for longitude of lunar apogee. This is nearly the same as the modern form of evection of which a part has been combined with the equation of centre, the difference being that Muñjāla's constant is 144′ while the modern value, as shown above, is nearly 153′. This inequality was also given by Śrīpati (A.D. 1039) in the manner expressed by Muñjāla but his constant was equal to 160′. Unfortunately the corrections suggested by these later astronomers were not accepted.

Coming down to Bhāskara II (A.D. 1150), we find that he catered for the third inequality of the Moon's motion known as 'variation' but his constant was 34′ in place of the correct value which was near to 40′. The equation for calculating inequalities of the Moon's motion as given by him was of the form

$$-379'.8 \operatorname{Sin} g_1 + 34' \operatorname{Sin} 2D$$

but this had the drawback for not containing any term for evection. Again Bhāskara's proposal to make correction to the Moon's mean motion by taking into account variation in addition to equation of centre was also not accepted.

The almanac makers of the country who follow the old conventional methods of *Sūrya-siddhānta* for calculating the position of the Moon take into consideration only the first term of the expression for calculating the inequalities in the motion of the Moon, namely the term—$300'.9 \operatorname{Sin} g_1$, and do not take into account the corrections required for other lunar inequalities. As such the position of the moon given in the almanacs which follow old conventional methods may differ sometimes as much

3° of arc which then causes a difference of 6 hours of time between the *pañcāṅgas* prepared on the above old conventional method and the modern method. It will, however, be interesting to note that the second and third term of the expression given for evection and variation, and also the term for the second inequality of the moon's motion as given by Muñjāla and Śrīpati, and so also the term for third inequality indicated by Bhāskara, vanish when D equals 0° or 180°, that is, when it is new moon or full moon, only the first term for inequality comes into play.

As regards the equation of centre of the Sun, the modern value of its principal term is 115′.2 Sin g', and in A.D. 500 it was 119′.1 Sin g′, slightly greater than its present value. The early Indian astronomers, however, adopted the term 131′ Sin g′ for this purpose which gives a little higher value. But this discrepancy can be explained if we consider the fact that the astronomers of that time gave more attention in correctly determining the difference between the longitudes of the Sun and the Moon, particularly for finding out the time for new moon and full moon. It will be seen that if the values of solar and lunar inequalities depending on g′ only (mean anomaly of the Sun) are considered for calculating the difference in angle between the Sun and the Moon, then it's value for the year 500 A.D. will work out as follows :

$$S_L - M_L = 119'.1 \text{ Sin } g' - (-11.6\ g') = 130'.7\ g'$$

and this is the value which has been used by the early Indian astronomers.

Note :—11′.6 g' was the value in A.D. 500 of the Moon's inequality for annual equation, present value being — 11′.2 Sin g'.

RAPID CHANGE OF THE MOON'S ORBIT AROUND THE EARTH

No celestial body of the solar system other than the Moon has such a complex motion, and this is reflected in the necessity of adding the values of a very large number of inequality terms to the mean position of the Moon to find its true position, and the principal inequalities in this respect have been dealt with in the previous paragraphs. The complexity in the Moon's motion is caused by the fact that the Moon being a body of very much smaller mass than the Sun and the Earth around which it moves, its motion is constantly perturbed by their gravitational pull on its tiny body causing constant and rapid change of the direction of the line of apsides and of the nodes of its elliptical orbit around the Earth, that is, the position of the Moon's orbit in space in relation to the Earth's orbit changes constantly in a very rapid manner. No doubt the change of the direction of the apse line and of the line of the nodes is a normal happening of the elliptical orbits of all the planets, but in the case of Moon this change takes place extremely rapidly as will be seen from the figures given in this respect both for the planets and the Moon in Table 9.7. This rapid change of the Moon's orbit will be better understood from the perusal of the illustration given in Fig. 9.1. It should be stressed that calculation of the true posttion of the Moon, which is a fundamental requirement in the framing of the lunar calendar and *Pañcāṅga*, is a very complicated process, and requires the use of up-to-date formulae and also advantageously that of a computer and this can be done by an establishment organised for this purpose.

Table 9.7. *Mean motion and the period of revolution of the perihelia and the nodes of (A) the Planets*[a] *and (B) the Moon*[b]

A. *Planets*[c]

Planet	Perihelion: Sidereal motion per Julian century	Perihelion: Julian centuries to complete one revolution	Node: Sidereal motion per Julian century	Node: Julian centuries to complete one revolution
Mercury	573″	2261.8	— 760″.6	1730.9
Venus	38	34105.3	—1787.0	725.2
Earth	1163	1114.4	—	—
Mars	1599	810.5	—2252.4	575.4
Jupiter	772	1678.8	—1388.8	933.2
Saturn	2025	640.0	—1885.0	687.5

B. *Moon*

	Mean Motion per day	Number of Julin years to complete one revolution	Mean motion per day	Number of Julian years to complete one revolution
Moon	400″.92 or 40°.677 per Julian year	8.85	—190″.77 or —19°.355 per Julian year	18.60

Note : Julian century = 36525 days; (—) means that motion is retrograde or clockwise; or east to west.

a. Figures obtained from Positional Astronomy Centre.

b. Figures taken from Lahiri's *Indian Ephemeris* and *The Moon* by Markov (Page 8), University of Chicago.

c. Note : *Sūrya-siddhānta's* values of mean motion or revolutions of perehelions and nodes per century for the planet, which are not accurate, are respectively as follows: (A) Aphelia; 11″.04, 16″.05, 11″.61, 6″.12., 27″.00 and 1″.17, and (B) Nodes:—14″.64, —27″.09 —27″.09 —6″.42, —5″.22, and —19″.86 (Ref. B.J.S. Part II—page 70). For the Moon, the *Sūrya Siddhānta* values are almost the same as shown jn Table 9,10.

LEGEND

X-X
Line of major axis of the earth's elliptical orbit

Y-Y
Line of minor axis of the above orbit

M-M′
Apse line (line of major axis) of the moon's elliptical orbit which rotates in a direction anti-clockwise (west to east) direction through an angle of about 40°-41′ (mean value) annually.

N-N′
Line of nodes of the moon's orbit, which is the line of intersectien of the plane of the moon's orbit with the plane ot the earth's orbit, the former being inclined to the latter by 5°-9′ (mean value), and which rotates in a retrograde or clockwise (east to west) direction through an angle of about 19°-21″ (mean value) annually.

A, B, C, D & A′
Configuration of the earth-moon system at positions 90° apart beginning with 'A' at aphelion point of the earth's orbit and ending at the same point as 'A' after making a complete revolution of 360°.

X-X′
Line parallel to x-x drawn at the two ends of the minor axis of the earth's orbit.

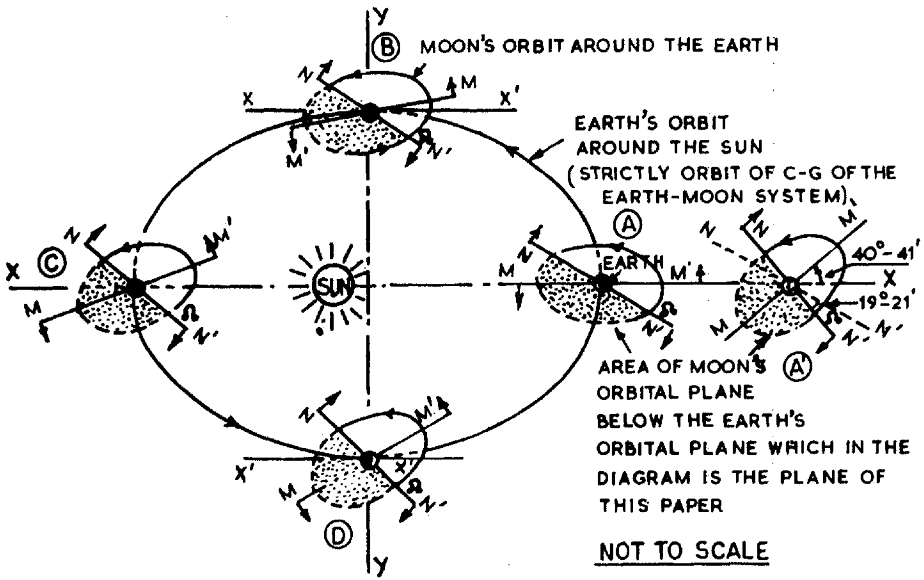

Fig. 9.1. DIAGRAM OF THE EARTH-MOON SYSTEM REVOLVING AROUND THE SUN

It shows

(a) The rotation of the "Line of Nodes" of the Moon's orbit in a clockwise or retrograde (east to west) direction which from the earth is observed as the regression of the nodes along the ecliptic, and

(b) The rotation of the apse line of the elliptical orbit of the moon in an anti-clockwise or direct (west to east) direction.

The early astronomers of he *Sūrya-siddhānta* period (A.D. 300-400) were not fully conversant with all the complexities of the Moon's motion as full knowledge about this was acquired much later, and as such all the corrections required to compute the true positions of the Moon could not possibly be incorporated in the *Sūrya-siddhānta* composed about 1500 years back. But the pity is that a large number of *pañcāṅga* pundits still continue to base their calculations on the longitude of the Moon as obtained from the formulae given in this book which have long become out of date. Now full knowledge on the subject is available, and the correct geocentric position of the Moon, the Sun, and the planets are embodied in the modern ephemerides, and it is inappropriate not to avail of this correct information to calculate the *tithis* on which our lunar calendar is based, and also other items like *nakṣatras* etc. It should be pointed out that our early astronomers were not at all averse to adopt advanced methods of astronomical calculations even though it might not have been fully indigenous in origin. It is generally accepted, as has been mentioned earlier, that an appreciable portion of the then advanced knowledge of astronomy embodied in *Sūrya-siddhānta* was obtained from outside sources. There is nothing wrong in it because advanced knowledge from whatever source it is available should be obtained to increase the level of knowledge and adapted suitably to meet the needs of the country and the society in a better manner, and this good principle should be followed by our present-day *pañcāṅga* makers by using correct longitudes of the Moon and the Sun and the planets as given in modern ephemerides, and they should not remain complacent with the old knowledge which has gone out-of-date long time back. Even the present-day astronomers of the advanced countries constantly revise their constants to keep pace with the new knowledge acquired in the science of astronomy.

Pancanga or Indian Almanac

Pañcāṅga is a very important book published yearly and is the basic book of the society giving calendrical information of various nature on daily basis, and is extensively used by the people all over India. This publication is also one of the basic books of the astrologers for making astrological calculations, casting horoscopes, and for making predictions. It is also used considerably by a large section of the people as an astrological guide book for finding out auspicious time for undertaking various social and other activities and the inauspicious time for avoiding such activities. This book shows the date and time of various religious festivals, and is used by the priests for determining the auspicious moments for carrying out various religious rites, and as such it is a fundamental book which is referred to by a very large section of the people in this country.

The very word *pañcāṅga*, however, means that the book comprises of five limbs or parts, which are as folows :

(a) *Vāra*, that is, week day;

(b) *Tithi*, that is, lunar day. If is indicative of the phase of the Moon.

(c) *Nakṣatra*, that is, position of Moon in the *nakṣatra* division.

(d) *Yoga* means literally addition. It is the time period when the longitudinal motions of the Sun and the Moon when added amounts to 13° 20′ or its integral multiple.

(e) *Karaṇa* means half period of a *tithi*.

The *pañcāṅga* apart from providing information on the five items mentioned in the preceding paragraph and giving a calendar of all the forthcoming religious events of the year, furnishes additional information on ephemerides of the Sun, the Moon, nodes of the Moon, and planets, sun-rise and sun-set timings, and other astronomical informations, which are extensively used by the astrologers. Further, the *pañcāṅga* gives the solar day of the month in the region where solar calendar is in use, Gregorian calendar date, sometimes national calendar date, and date of the lunar month in the regions where lunar calendar is followed. Let us look into detail the main items which form the *pañcāṅga*.

Vāra or Weekday

It is interesting to note that this calendric item is used by all calendars of the world maintaining the same name sequence and serial order of the days in the cycle of 7-days which comprise the week. This obviously proves that this innovation has spread out from one source, and luckily has been adopted by all calendars of the world without any change.

The device of continuously counting the days in the short cycle of 7 days without directly linking it to any astronomical phenomena like the yearly or monthly cycles of the Sun or the Moon, or to lunar phases, was indeed a magnificient step forward in simplifying the calendar for easy use by the people because it provided a very easy method for ear-marking the day of rest, the day for religious services, and for fixing ahead certain days for activities to be undertaken within a short period without reference to any complicated religious calendar or to priests, which were often inconvenient and time consuming. This practical device caught the imagination of the people all over the world and found universal acceptance.

The cycle of 7-days, known as week, had an astrological origin. The Chaldeans believed that the seven luminaries in the sky, namely, the Sun, the Moon, Mercury, Venus, Mars, Jupiter, and Saturn, which were observed by them to move continuously against the background of stars, were really the gods who together controlled the destinies of the kings and men. Each of these planetary gods had a name, and they were placed in a serial order starting from the one which is farthest in the heavens, and ending with one which is closest, as shown in Table 9.8.[21]

Table 9.8. *Chaldean origin of Week-days after planetary gods*

Serial number for the planetary gods	Planets	Chaldean god-names	Function of the gods
1	Saturn	Ninib	God of Pestilence & Misery
2	Jupiter	Marduk	King of Gods
3	Mars	Nergal	God of War
4	Sun	Shamash	God of Administration and Justice
5	Venus	Ishtan	Goddess of Love and Fertility
6	Mercury	Nabu	God of Writing
7	Moon	Sin	God of Agriculture

Further, the period covering the day and the night was divided into 24 equal parts which is hours and each of the seven gods was supposed to keep a watch on mankind over each of 24 hours of the day and night in rotation and the day (which includes night) was named after the Planet god which ruled the 1st hour of that day. According to this belief, the ruling of the successive days by the planetary gods after which the days are named take the following pattern:[22]

	Saturday												*Sunday*
Hours	1	2	3	4	5	6	7	8....14 ..	15..21..22		23	24	25(1)
Gods watching	1	2	3	4	5	6	7	1.... 7	1.. 7	1	2	3	4
	(Saturn)												(Sun)

	Sunday							*Monday*
Hours	1	2	3	4	5 — 11	12—18	19 — 24	25(1)
Gods watching	4	5	6	7	1 — 7	1 — 7	1 — 6	7
	(Sun)							(Moon)

The above sequence of naming the days of the week was adopted in the course of time by all nations of the world including India where the week-days were named as Ravi, Soma, Maṅgala, Budha, Bṛhaspati, Śukra, and Śaṇi which are the Indian names for the planets or planetary gods. The English names Tuesday, Wednesday, Thursday and Friday are adoption from the names of the Teutonic deities Tiu, Woden, Thor, and Freya which are counterparts of the Roman planetary deities

Mars, Mercury, Jupiter, and Venus.[23] It is significant to note that the functions attributed by the Chaldeans to their planetary gods are the same as given by our astrologers, and hence it seems that the Chaldean planetary astrology along with the Chaldean method of naming the week-days had a widespread influence.

The continuous counting of the days in a cycle of 7 days was not in use amongst ancient Hindus, classical Greeks and Romans, and early Christians. The names of seven days of the week are not found in the Vedas. There is no reference to the use of week-days in the *Mahābhārata.* In one verse of the *Vedāṅga Jyotiṣa* (Atharva), the names of the Sun, the Moon and the five planets have been mentioned in the same order as the days of the present-day week and these have been called as "Lords of the Days". In *Yājñavalkya Smṛti* there is also mention of the Sun, the Moon and the planets as per names of the days of the week, but it is followed by the name of Rāhu and Ketu, and these are not mentioned as lords of the days. Any way, there is no explicit mention of the use of seven-day weekly cycle in our ancient religious books and epics. The use of week days filtered in our country from outside and gradually established a place in our calendar.

The inscriptional evidence of the use of week-day in India is first found in the inscription of Emperor Budhagupta which is dated as Thursday, the 12th lunar day of the bright half of Āṣāḍha in Gupta year 165 which corresponds to A.D. 484.[24] In the Christian world, the week-day system was introduced by the Roman Emperor Constantine at about 323 A.D., and he made Sunday to be the weekly prayer day (Lord's day) for the Christians, this day being different from Saturday which had the Sabbath day for the Jews. There is no mention of week days in the New Testament. The present Christian belief that Jesus Christ was crucified on Friday, known as Good Friday, and ascended 'heaven' on Sunday, celebrated as Easter Sunday, seems to be a later concoction.

In determining the days of the old traditional Hindu religious festivals, the week days do not come into play like fixing of the dates of the Christian religious festivals, like Easter. This is perhaps because when these days come to be fixed, week days in the present form did not either then come into use or have so much of prominence or influence. It is later that week days permeated into our society in a great way and exerted influence in the performance of many religious and social activities. Now specific days of the week are earmarked for worshipping various gods and for observing fasts for them. Also in many astrological matters week days play a prominent role. The time span of the day and night periods of each of the day of the week have been divided separately into eight parts and each of these parts is considered to have an astrological significance of having either good or bad influence for undertaking activities–both religious and social. Again in astrological calculations for determining auspicious and inauspicious moments for undertaking journeys or also other activities, the week days play quite often a vital role in combination with *tithis* or *nakṣatras,* and as such the man-made week days, which have no link with any astronomical phenomena, have gradually established them selves in our religious and social life.

Tithi

Tithi is a very important item of the *pañcāṅga*. It is on the basis of the *tithi* that most of our religious festivals and functions are fixed. In the luni-solar calendar *tithi* plays the prime role because on its basis again the days of its months are counted.

Tithi has been in use in the Vedic times but at that time it was reckoned in a manner different from the *Sūrya-siddhānta* method that is followed now, it being then concerned only with the Moon. In the *Aitareya Brāhmaṇa* (32.10), *tithi* has been defined as that time-period about which the Moon sets or rises. It has been interpreted by Prof. P. C. Sen Gupta to mean that during *śukla pakṣa* when only moon-set can be observed in the night, it was the time period from moon-set to moon-set. In *kṛṣṇa pakṣa* when only moon-rise can be observed in the night, it was the period from moon-rise to moon-rise. The lengths of the *tithis* were thus unequal.

During *Vedāṅga Jyotiṣa* times *tithi* was also mainly connected with the Moon. It was defined, as mentioned earlier, as 1/30th of the period of the lunar synodic month, and there being 1860 *tithis* during 5-year *yuga* period of 1830 days, the length of a *tithi* works out as 1830/1860 day = 0.98387 day.

Tithi that is followed now is the one which is laid down in the *Sūrya-siddhānta*[25] and it is different from the two patterns mentioned above. In the present system the positions of both the Moon and the Sun come into play for determining the *tithi* for any day. The *Sūrya-siddhānta* astronomers introduced a new astro-mathematical conception of the *tithi* by giving it the definition on the basis of the difference of longitudinal angle between the position the Moon and the Sun. There are a total of 30 *tithis* 15 during *śukla pakṣa* and 15 during *kṛṣṇa* and hence the *tithi* has been defined as the time period during which the angular distance of the Moon from the Sun in longitude increases by 12° or its integral multiples. The *tithis* or *tithi*-days in the case of *amānta* lunar calendar begins from new-moon, and thus the first *tithi śukla pratipada* commences when the longitude of the Moon and the Sun are the same, and it ends when the difference increases to 12°. At that moment also the *śukla dvitīyā tithi* starts and it ends at the time when the Moon gains 24° over the Sun, and so on. Thus *pūrṇimā* will cover the period of time when the angular difference in longitude of the Moon from the Sun increases from 168° to 180°, that is, its ending moment will be when the Moon and the Sun are in opposition, and that moment is known as full-moon. Similarly *amāvasyā* will cover the period when this difference will increase from 348° to 360° which is 0°. This means that the ending moment of *amāvasyā* will take place when the Moon and the Sun are in conjunction, and that moment is known as new moon. In the case of *pūrṇimānta* calendar, the counting of *tithis* start from the full-moon so the first *tithi*, which is *kṛṣṇa pratipada*, commences when the longitude of the Moon in relation to the Sun is 180°, and the next *tithi* or *tithi*-day which is *kṛṣṇa dvitīyā*, begins when this difference increase to 192°, and so on.

The *śukla tithis* are the periods when the Moon waxes and *kṛṣṇa tithis* are the periods when the Moon wanes, and both the set of *tithis* have the same name designations except that these are prefixed respectively by the words *śukla* and *kṛṣṇa*. The name of the fifteen tithis along with their ordinal numbers by which they are some-

times expressed are shown below. It will be noticed that amāvasyā is given the number 30 and not 15 as per normal serial order and it is done in the case of *pūrṇimā*:

1. Pratipada	6. Saṣṭhī	11. Ekādaśī
2. Dvitīyā	7. Saptamī	12. Dvādaśī
3. Tṛtīyā	8. Aṣṭamī	13. Trayodaśī
4. Caturthī	9. Navamī	14. Caturdaśī
5. Pañcamī	10. Daśamī	15. Pūrṇimā
		30. Amāvasyā

The *śukla* and *kṛṣṇa tithis* are differentiated by putting prefix '*S*' and '*K*' respectively which mean that 15 *śukla tithis* are numbered from *S*1 to *S*15 and 15 *kṛṣṇa tithis* from *K* 1 to *K* 14 for the first 14 *tithis* and *K* 30 for the last *tithi*, which is *amāvasyā.*

The mean synodic period of the Moon (in mean solar days) is 29.530 588 days = 29 days 12.73 hours = 29 days 12 hours 44 mins, and there being 30 *tithis*, the average duration of a *tithi* works out as 0.984 353 days = 23.62 hours = 23 hours 37.5 mins. In *Sūrya-siddhānta* the motions of the Sun and the Moon taken for making calculations are true motions, and not mean motions as followed in *Vedāṅga Jyotiṣa* calendar. Due to various perturbing forces the true motions of the Moon and also of the Sun particularly the former, are not uniform. As a matter of fact the true motion of the Moon may vary from 15° 23′ to 11°46′ from day to day. For this reason the duration of *tithis* varies widely. The average duration of the *tithi* is 23 hours 37.5 minutes, but the actual duration of a particular *tithi* may be as large as 26 hours 47 minutes or it may be as small as 19 hours 59 minutes. Similarly the average length of the lunar month is 29 days 12.73 hours, but its actual length varies from 29 days 5.9 hours to 29 days 19.6 hours.

All the above figures are based on the correct true motion of the Sun and the Moon, and are unlikely to agree with the figures given by the *pañcāṅgas* following the old conventional values which are based on the longitudes of the Sun and Moon calculated as per formulae given in *Sūrya-siddhānta* which for the Moon take care of the corrections for the equation of the centre only and do not take into account other corrections required to get its longitude for the true observed position, and as a result the *tithi* timings shown by the *pañcāṅgas* following old conventional school differ greatly from *pañcāṅgas* which follow modern ephemeris of the Sun and the Moon. As an example, the timings of the beginning and ending moments of *kṛṣṇa Āṣāḍha aṣṭami* (*amānta* calendar) of 1904 Śaka, covering 13th and 14th July 1982, as given in old traditional *pañcāṅgas* calculated as per *Sūrya-siddhānta* constants and as given in modern *pañcāṅga* calculated on the basis of values given in modern astronomical ephemeris, have been shown below for the sake of comparison:

Gregorian calendar date	Āṣāḍha *kṛṣṇa* aṣṭamī *tithi* (*amānta* calendar)		Traditional *Pañcāṅga* based on *Sūrya-siddhānta*[26]	Modern *Pañcāṅga* based on modern ephemeris[27]
13 Jul '82	Begins	—	17 hrs 13 mins	21 hrs 41 mins
14 Jul '82	Ends	—	16 hrs 04 mins	20 hrs 43 mins

In this connection it may be pointed out that a number of *pañcāṅgas* which base their calculations on the *Sūrya-siddhānta* system and constants follow a convention called *bāāavṛdhi rasakṣaya* which means that the actual *tithi* timings calculated on the basis of true motions of the Sun and the Moon obtained after applying various corrections should not exceed the *tithi* timings calculated on the basis of mean motions of the Sun and the Moon by a period more than 5 *daṇḍas* or *ghaṭis*, that is by 2 hours, and should also not be less than that timing by a period more than 6 *daṇḍas* or *ghaṭis*, that is by 2 hours 24 minutes. This is an arbitrary convention and is not mentioned anywhere in the text of *Sūrya-siddhānta*.

The length of the lunar month is only 29.53 days but it is counted as 30 days on the basis of 30 *tithis* and as such certain adjustment in the counting of days of lunar month on the basis of *tithis* becomes inevitable to have the month beginning from the new moon day or from full-moon as the case may be.

The day of the Indian calendar begins with sunrise, and covers the period till the next sunrise. Therefore in counting the days of the lunar month, the *tithi* that is prevalent at sunrise is considered to be the *tithi* of the day, and the ordinal number of this *tithi* is taken as the day-number of the lunar month. But the time in the day (including night) when a *tithi* ends and the next one begins do s not remain fixed. This is because the average length of a *tithi* is less than 24 hours and also because the true motions of the Sun and the Moon being not uniform, there is an appreciable difference between the starting time of the *tithis*. This results in a *tithi* sometimes beginning and also ending between two consecutive sunrises, that is, there is no sunrise during the period of duration of a *tithi*, and such a *tithi* is known as a *kṣaya tithi*. In that case the ordinal number of that *tithi* day is omitted from the serial number of the days of the lunar month, thus causing a break in the seriality of the days of that month. In Bengal the *kṣaya tithi* day is known as *tryahasparśa*, literally meaning the touching of three (lunar) days, and actually three *tithis* (one full and portions of two) happen to cover one civil day from sunrise to sunrise, and it is deemed to be inauspicious. As opposed to the above, a *tithi* may extend on both sides of the civil day, that is, there are two sunrises during a *tithi*, and such a *tithi* is known as an *adhika tithi*, and is counted twice in the serial number of the days of the month. The days of the lunar month are counted, as already mentioned, in accordance with the ordinal number of the *tithi*. occurring at sunrise, and hence when a *kṣaya tithi* occurs, the ordinal number of the day of the *tithi*, which is a *kṣaya tithi*, is dropped in numbering the days of the month, and when an *adhika tithi* occurs, the ordinal numbers of that *tithi* is repeated, for *example*, if in the first half of the lunar month *tṛtīya tithi* is a *kṣaya tithi*, the sequence of the days of the month will be 1, 2, 4, 5, etc. Again if *caturthi tithi* is an *adhika tithi*, the sequence of the days will take the form 1, 2, 3, 4, 4 *(adhika)*, 5, etc.

Tithi is calculated on the geocentric longitudes of the Sun and the Moon, and hence, it being a geocentric phenomena, a *tithi* begins and ends at the same time at all places of the world. It may be interesting to note that if topocentric longitude is

taken for calculation, the longitude for the Moon will differ from one place to another, and as such the timings of the beginning and ending moments of tithis will vary.

Nakṣatra

Nakṣatra is another important item of the *pañcāṅga*. The mean value of the sidereal period of the revolution of the Moon in mean solar days is 27.321 66 days= 27 days 7 hours 43.19 minutes. The apparent yearly path of the Sun seen from the Earth on the background of stars is known as the ecliptic. The Moon and almost all the planets excepting Pluto are found within a belt of width 8° on either side of the ecliptic, and this belt is known as 'zodiac', or *Rāśicakra*. To indicate day to day position of the Moon in relation to the stars this zodiac has been divided into 27 equal parts from a fixed initial point in the ecliptic, and each of this part is known as *nakṣatra,* meaning really *nakṣatra* division, and covers 13° 20′ or 800′ minutes of arc of the ecliptic. Each *nakṣatra* division is named after a selected star which is generally prominent or traditionally well known and is broadly equally spaced in the zodiac, and these identifying stars are known as *yogatārās*, and are mostly located in the lune covering that *nakṣatra* division. There are, however, a few *yogātārās* like Ārdrā, Svātī, Jyeṣṭhā, Pārvāṣāḍhā, Uttarāṣāḍhā, Śravaṇa, and Dhaniṣṭhā which are located outside the lune covering the above named *nakṣatra* divisions. The work *nakṣatra* in *pañcānga* means the position of the Moon in the particular *nakṣatra* division signified by its name.

The beginning or initial point of *nakṣatra* divisions has changed from time to time. In the Vedic period Kṛttikā (η Tauri) was reckoned to be the starting star and the point for counting the *nakṣatras;* during *Vedāṅga Jyotiṣa* period the year started from Dhaniṣṭhā (β Delphini), and the counting of *nakṣatra* division may be assumed to have commenced from there though nothing specifically is mentioned about it in the text. During the later period of compilation of the *Mahābhārata nakṣatras* started from Śravaṇa (Attair—α Aquilae). *Sūrya-siddhānta* astronomers changed the initial point for counting the *nakṣatra* divisions to a point in the ecliptic opposite the star Citrā (Spica—α Virginis). The spring equinox coincided with this initial point at A.D. 285 and by c A.D. 400 when the *Sūrya-siddhānta* system became current, the equinoctial point was located not very far from this point. There is a school which is of the view that the *Sūrya-siddhānta nakṣatra* divisions commence from Revati (ζ Piscium), but most of the *pañcāṅga* makers now follow the Citrā school. Sometimes at an earlier period the *nakṣatra* Abhijit has been mentioned, the star being identified with Vega (α Lyrae), but this is not included now in the list of *nakṣatras*.

The name of 27 *nakṣatra* divisions along with the *nirayana* longitudes of their beginnings and the longitude and latitudes of *yogatāras* (identifying stars) after which the *nakṣatra* divisions are named, are shown in Table 9.9 (28).

Yoga

Yoga literally means addition. This item of *pañcāṅga* means the period during which the sum *(yoga)* of the *nirayana* longitudes of the Sun and the Moon amounts to 13° 20′ or its integral multiples. The first *yoga* Viskumbha ends when the sum amounts to 13° 20′ and the second *yoga* Prīti commences. The second *yoga* similarly

Table 9.9. *Position of Yogātārns or Identifying Stars in Nakṣatra Divisions*

Sl. No. of *nakṣa-tras*	Name of *nakṣatras* (*nakṣatra* divisions)	*Nirayana* longitude of the beginning of *nakṣatra* divisions	Name of *yogatārās* (idenuifying stars) of *nakṣatra* divisions	*Niryana* longitude of the *yogatārās*	Latitude of the *yogatārās*	Position of *yogatārās* in the *nakṣatra* division
1	2	3	4	5	6	7
1	Aśvinī	0° 0′	β Arietis	10° 07′	+ 8° 29′	10° 07′
2	Bharaṇī	13 20	Arietis	24 21	+10 27	11 01
3	Kṛttikā	26 40	η Tauri	36 08	+ 4 03	9 28
4	Rohiṇī	40 00	α Tauri	45 56	— 5 28	5 56
5	Mṛgaśiras	53 20	λ Orionis	59 51	—13 23	6 31
6	Ārdrā	66 40	α Orionis	64 54	—16 02	(—) 1 46*
7	Punarvasu	80 00	β Geminorum	89 22	+ 6 41	9 22
8	Puṣyā	93 20	δ Cancri	104 52	+ 0 05	11 32
9	Aśleṣā	106 40	α Cancri	109 47	— 5 05	3 07
10	Maghā	120 00	α Leonis	125 58	+ 0 28	5 58
11	Pūrva Phalguni	133 20	δ Leonis	137 27	+14 20	4 07
12	Uttara Phalguni	146 40	β Leonis	147 46	+12 16	1 06
13	Hasta	160 00	δ Corvi	169 36	—12 12	9 36
14	Citrā	173 20	α Virginis	179 59**	— 2 03	6 39
15	Svātī	186 40	α Bootis	180 23	+30 46	(—) 6 17*
16	Viśākhā	200 00	α Libra	201 14	+ 0 20	1 13
17	Anurādhā	213 40	δ Scorpii	218 43	— 1 59	5 23
18	Jyeṣṭhā	226 40	α Scorpii	225 54	— 4 34	(—) 0 46*
19	Mūla	240 00	λ Scorpii	240 44	—13 47	0 44
20	Pūrvāṣāḍhā	253 20	δ Sagittarii	250 43	— 6 28	(—) 2 37*
21	Uttarāṣāḍhā	266 40	σ Sagittarii	258 32	— 3 27	(—) 8 08*
22	Śravaṇa	280 00	α Aquilae	277 55	+29 18	(—) 2 05*
23	Dhaniṣṭhā	293 20	β Delphini	292 29	+31 55	(—) 0 51*
24	Śatabhiṣaj	306 40	λ Aquarii	317 43	— 0 23	11 03
25	Pūrva Bhādrapadā	320 00	α Pegasi	329 38	+19 24	9 38
26	Uttara Bhādrapadā	333 20	γ Pegasi	345 18	+12 36	11 58
27	Revatī	346 40	ξ Piscium	356 01	— 0 13	9 21

Note : (a)** The *nirayana* longitude of the Citrā (α Virginis) was 180° at A.D. 285 from the initial point of the *nirayana* zodiac which was fixed at that time. Due to proper motion the star Citrā is moving in the negative (clockwise) direction and its *nirayana* longitude from the fixed initial point has now decreased to 179°59′.

(b) * The stars Ārdrā, Svātī, Jyeṣthā, Purvāsādhā, Śravana and Dhanisṣhā and located outside the lunes of the *nakṣatra* divisions of the same name, and all of them are positioned in the preceding *nakṣatra* divisions by the amount shown.

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ends when this sum amounts to 26°40′, and the third one Āyusmān commences, and so on. Thus the last *yoga* Vaidhṛti ends when the sum becomes 360°, and the first *yoga* Viṣkumbha starts again. The name of the 27 *yogas* in the serial order of their occurrence are noted below.

1. Viṣkumbha	10. Ganda	19. Parigha
2. Prīti	11. Vṛddhi	20. Śiva
3. Āyusmān	12. Dhruva	81. Siddha
4. Saubhāgya	13. Vyāghāta	22. Sādhya
5. Śobhana	14. Harshana	23. Śubha
6. Atiganda	15. Vajra	24. Śukla
7. Sukarmā	16. Siddhi	25. Brahma
8. Dhṛti	17. Vyatipāta	26. Indra
9. Sula	18. Variyān	27. Vaidhriti

Yoga is an entirely arbitrary device. It does not convey any physical conception nor it is found to have any assignable relation with any astronomical phenomenon or with any asterism. It was probably introduced later for astrological purposes, and even if it is so, it does not seem to be very much used these days. The *Pañcasiddhāntikā* indicates the method for calculating the *tithi* and the *nakṣatra,* but does not mention the method for calculating *yoga*. Āryabhaṭa has also not mentioned anything about *yoga*. Therefore it seems that *yogas* did not exist during Varāhamihira's time. Again Brahmagupta has mentioned about *nakṣatra,* like *karāṇa,* but not about *yoga*. There is a couplet though about *yoga* in Brahmagupta's *Khaṇḍakhādyaka,* but scholars are of the opinion that it is a later interpolation. Al-Bīrūnī in his comments on this book, has not mentioned anything about *yoga*. It therefore seems that *yoga* did not form form part of the *pañcāṅga* till about 700 A.D. or so.[29]

Karaṇa

Karaṇa is half of a *tithimāna,* each *tithi* having two *karaṇas*. A *karaṇa* is, therefore, completed when the Moon gains every 6° on the Sun. But the number of *karaṇas* is very much restricted, and does not have the same pattern as followed in the case of *tithis, nakṣatras,* or *yogas,* There are seven normal *karaṇas,* namely 1. Bava, 2. Bālava, 3. Kaulava, 4. Taitila, 5. Gara, 6. Vinij, and 7. Vishti. There are four other special *karaṇas* known as *sthira karaṇa,* and these are 1. Śakuni, 2. Nāga, 3. Catuṣpada, 4. Kiṃtughna. The four *sthira karaṇas* occur only once in a cyclic order. The above four *sthira karaṇas* occupy the periods of the half *tithis* respectively as follows: (1) the second half-*tithi* of *kṛṣṇa caturdaśī* is Śakuni, (2) the first half-*tithi* of *amāvasyā* is Nāga, (3) the second half-*tithi* of *amāvasyā* is Catuṣpada, and (4) the first half-*tithi* of *śukla pratipada* is Kiṃtughna. From the second half of *śukla pratipada,* the seven normal *karaṇas* repeat in a cyclic order eight times and then are followed by four *sthira karaṇas,* and thus all the 60 half-*tithis* of a lunar month are covered. The Table 9.10 shows the manner in which 60 half-*tithis* of a lunar month are given the name of different *karaṇas*.

Reference regarding the use of Karaṇa is not found in the earlier books like *Mahābhārata* (400 B.C.). It was introduced much later probably about 400 A.D. or so.[30] In the present context, it does not seem to have any special significance over the tithis which is really the basic item, and also no reason can be found for having the names and cycles in the manner described above.

Rāśi

Apart from the five items which originally *pañcāṅga* was taken to comprise of, there are other important items of information which this annual publication from different regions now provide. One of this is *rāśi*. It means that when the zodiac belt is divided into 12 equal parts from an initial point each part is known as *rāśi* covering 30° of arc of the ecliptic. In the *nirayana* system, which is followed by all our *pañcāṅgas*, the initial point is taken to be a fixed one in the zodiac, and normally this point is taken to be that which is opposite the star Citrā (Spica—α Virginis), that is, from this initial point the longitude of Citrā measures 180°. This initial point is located on the east of the vernal equinoctial point, and the angular distance in longitude of these two points is known as *ayanāṃśa*. As mentioned earlier, due to precessional motion of the Earth, the vernal equinoctial point is regressing in the westerly direction, and as such *ayanāṃśa* is constantly increasing, and its value on 1 Jan 1984 was 23°37.′7. The twelve *rāśis* in the serial order counted from the initial point are Meṣa, Vṛṣabha, Mithuna, Karka or Karkaṭa, Siṃha, Kaṇyā, Tulā, Vṛṣcika, Dhanus, Makara, Kumbha, and Mīna. It is to be mentioned that the initial point of the *nakṣatra* divisions and that of the *rāśi* divisions is the same, and hence each *rāśi* division starting from the first one, which is Meṣa, covers successively 2¼ *nakṣatra* divisions.

Table 9.10. *Table showing the disposition of Karaṇas in relation to half-tithis of a lunar month*

Tithi	Name of Karaṇas			Name of Karaṇas	
	1st half of *tithi*	2nd half of *tithi*		1st halfof *tithi*	2nd half of *tithi*
S_1	Kimtughna*	Bava	K_1	Bālava	Kaulava
S_2	Bālava	Kaulava	K_2	Taitila	Gara
S_3	Taitila	Gara	K_3	Vanij	Visti
S_4	Vanij	Visti	K_4	Bava	Bālava
S_5	Bava	Bālava	K_5	Kaulava	Taitila
S_6	Kaulava	Taitila	K_6	Gara	Vanij
S_7	Gara	Vanij	K_7	Visti	Bava
S_8	Visti	Bava	K_8	Bālava	Kaulava
S_9	Bālava	Kaulava	K_9	Taitila	Gara
S_{10}	Taitila	Gara	K_{10}	Vanij	Visti
S_{11}	Vanij	Visti	K_{11}	Bava	Bālava
S_{12}	Bava	Bālava	K_{12}	Kaulava	Taitila
S_{13}	Kaulava	Taitila	K_{13}	Gara	Vanij
S_{14}	Gara	Vanij	K_{14}	Visti	Sakuni*
S_{15}	Visti	Bava	K_{30}	Nāga*	Chatuspada

Note : (a) S_1, S_2 etc. denote śukla pratipada, śukla dvitiyā, etc., and K_1, K_3 etc denote Kṛṣṇa pratipada, Kṛṣṇa dvitiyā, etc; S_{15} denotes purnimā, and K_{30} amāvasya.

(b) *These are four sthira karanas which occur only once in a lunar month in the manner shown in the table.

In practice, the word *rāśi* conveys two meanings: One means the position of the Moon in the above twelve *rāśi* divisions at a specified time, which may at the time of birth, at the current moment, or at any other required time. For example, when it is said that a person's *rāśi* is Tulā, it means that when the person was born, the Moon was in that *rāśi* division. Similar meaning is also conveyed by the word *nakṣatra,* namely, when it is said that a person's *nakṣatra* is, say, Svātī, it means that at the time of his birth the Moon was in that *nakṣatra* division. Hence *rāśi* and *nakṣatra* as used, convey a calendrical meaning in indicating a period of time in which an event happened.

The other meaning of *rāśi* is the time period during which the Sun traverses the *rāśi* division, and is indicative of the *nirayana* solar month. As a matter of fact in Kerala and in some parts of Orissa, *nirayana* solar months of the *pañcāṅga* are in use for dating purposes, and these months are known by the names of *rāśi* divisions indicating that the Sun is positioned in that *rāśi* for the period covered by the month.

It will be interesting to note that the pattern and the names of *rāśi,* like the week days, are the same throughout the world, the only difference being that in western system the initial point for reckoning the *rāśis* is the vernal equinoctial point which is a retrograde moving point in the ecliptic while ours is a fixed point. The Babylonians and the Greeks had a similar set of names for the *rāśis,* known as zodiac signs, and in the same order, and Varāhamihira adopted the corrupted Greek names for naming the *rāśi* divisions as may be observed from Table 9.11.[31] *Rāśi* in the present form is not specifically mentioned in early ritualistic literature like Brāhmaṇas, or in the epic like *Mahābhārata.* It has, therefore, been inferred that *rāśi* names, as followed now, came to India as a result of contact with Macedonian Greeks and the Śakas when exchange of knowledge of astronomy took place resulting in the inflow of Graeco-Chaldean astronomy in the country.

It should, however, be said that division of the ecliptic into 12 parts can not be purely Graeco-Chaldean. Much before the Chaldeans, the Egyptians divided the solar year, which they followed, into 12 months. The Vedic Aryans had also 12 months Madhu, Mādhava, etc., covering the year. Later *Vedāṅga Jyotiṣa* calendar had also the 12-month system of counting the year. Perhaps specifically naming the divisions of the ecliptic after the name of animals and objects were not in use then, and this pattern of naming the 12 divisions of the ecliptic came into vogue not only in India, but throughout the world, like the week days, with the rise of Graeco-Chaldean astronomy.

Table 9.11. *Table showing the different names used for the Zodiacal Signs*

Beginning and ending points of the signs	English names of the Signs	Meaning of the English names	Babylonian names	Greek names	Names used by Varâhamihira	Present Indian names	Meaning of the Indian names
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
0°—30°	Aries	Ram	Ku or Iku	Krios	Kriya	Mesha	Ram
30—60	Taurus	Bull	Te-te	Tanros	Tābure	Vrishabha	Bull
60—90	Gemini	Twins	Masmasu	Didumoi	Jituma	Mithuna	Couple
90—120	Cancer	Crab	Nangaru	Kar-xinos	Kulira	Karka or Karkata	Crab
120—150	Leo	Lion	Aru	Leon	Leya	Simha	Lion
150—180	Virgo	Virgin	Ki	Parthe-nos	Pāthona	Kanya	Girl (Virgin)
180—210	Libra	Balance	Nuru	Zugos	Juka	Tula	Scales
210—240	Scorpio	Scorpion	Akrabu	Scorpios	Kaurapa	Vrischika	Scorpion
240—270	Sagitta-rius	Archer	Pa	Tozeutes	Taukshika	Dhanus	Bow
270—300	Capri-cornus	Goat	Sahu	Ligo-xeros	Akokera	Makara	Crocodile
300—330	Aquarius	Water-bearer	Gu	Garo-xoo s	Hydroga	Kumbha	Pitcher
330—360	Pisces	Fish	Zib	Ichthues	Antyabha	Mina	Fish

Note : The meaning of Greek and Babylonian name. for the Signs are the same as those shown for the corresponding English (Western) Signs.

Solar Month and Solar Year

The solar month and consequently the solar year are fundamental items on which the structure of the *pañcāṅga* or Indian calendar rests. The solar-year calendar is followed for indicating the dates of the year in the states of Tripura, Assam, Bengal, Orissa, Tamil Nadu, Kerala and partly Panjab and Haryana while the lunar calendar is followed in other states for the same purpose. But in all states for fixing the dates of religious festivals and for selecting auspicious time for undertaking many socio-religious activities, the lunar calendar is used. The lunar calendar, however, is pegged with the solar calendar, or more precisely, the lunar months are linked with the *nirayana* solar months to prevent these getting delinked from the seasons.

The *Sūrya-siddhānta* defines the solar month as the time taken by the Sun to traverse a *rāśi,* which is the difference between the time of ingress of the Sun to one *rāśi (saṃkrānti)* and to the time of ingress to the next one (next *saṃkrānci*). As Meṣa is the first *rāśi,* the time taken by the Sun to traverse this *rāśi* forms the 1st solar month, and it is called Meṣa in Kerala, and Vaiśākha in Tripura, Bengal, Orissa,

Haryana, and Punjab, Behag in Assam, and Chittirai in Tamil Nadu. The second solar month is similarly formed by the time taken by the Sun to traverse the second *rāśi*, which is Vṛṣava, and so on for other months. The names by which the 12 solar months are known in different regions where solar calendar is followed is shown in Table 9.12. It may be mentioned that solar year and solar month in the Indian calendar mean that they are sidereal or *nirayana*, and these qualifying words are sometimes prefixed to year and month to differentiate these from tropical or *sāyana* system.

Table 9.2. *Names of solar months in different regions*

Name of *Rāśis*	Tripura, Bengal Orissa, Haryana & Punjab	Assam	Tamil Nadu	Kerala	Some parts of North Kerala
1	2	3	4	5	6
1. Meṣa	Vaiśākha*	Bahāg*	Chittirai*	Meṣa	Medam
2. Vṛṣava	Jyaiṣṭha	Jeth	Vaikāsi	Vṛṣava	Edavam
3. Mithuna	Āṣāḍha	Āhār	Āni	Mithuna	Midhunam
4. Karkaṭa	Śrāvaṇa	Sāon	Ādi	Kartitaka	Kartitaka
5. Siṃha	Bhādra	Bhād	Āvani	Siṃha*	Chingam
6. Kanyā	Āśvina	Āhin	Purattāsi	Kanyā	Kanni*
7. Tulā	Kārtika	Kāti	Arppisi	Thulā	Thulam
8. Vṛścika	Agrahāyaṇa	Aghon	Kārthigai	Vṛścika	Vrischikam
9. Dhanus	Pauṣa	Puha	Mārgali	Dhanus	Dhanu
10. Makara	Māgha	Māgh	Thai	Makara	Makaram
11. Kumbha	Phālguna	Phāgun	Māsi	Kumbha	Kumbham
12. Mīna	Caitra	Chait	Panguni	Mīna	Minam

* The first month of the year.

It will be observed from Table 9.12 that all states except Kerala follow either the names Vaiśākha, Jyaiṣṭha, Āṣāḍha, etc or the local language versions of the same names for reckoning the different solar months. In Tamil Nadu, however, though the year starts from the 1st point of Meṣa *rāśi* and also follows the same serial sequence for the months like the other states, its months start with Chittirai (meaning Caitra) followed by Vaikāsi (meaning Vaiśākha), etc, as shown in the Table, but their time-periods correspond to the months of Vaiśākha, Jyaiṣṭha, etc of the other states, and this means that the months of the Tamil Nadu solar calendar are named a month ahead compared to the months of the solar calendar of the other states.

The name of the solar months, Vaiśākha, Jyaiṣṭha, etc. have been derived from the name of *nakṣatras* where full-moon, which may be taken to include the period of *pūrṇimā* in this case, is deemed to occur when the Sun is in the *rāśi* division with which the solar month is linked. But full-moon can occur when the Moon is in the

rāśi opposite the one where the Sun is placed, and each *rāśi* covers three nakṣatra divisions which may be one full and two part divisions or two full and one part division. In all years full-moon does not occur in the *nakṣatras* after which the year is named because full-moon occurs by turn in all 27 *nakṣatra* divisions, and also in a few cases the *nakṣatras* after which the month is named, may not be placed within the *rāśi* opposite to that of the Sun. The main criteria which appear to have been followed for choosing the *nakṣatras* were :

(a) the *yogatārās* or identifying stars of the *nakṣatra* divisions are the ones which are prominent or in a few cases like Pusya, have some traditional significance even though these may not be located exactly opposite to the *rāśi* division of the Sun, and

(b) these are placed broadly equally apart.

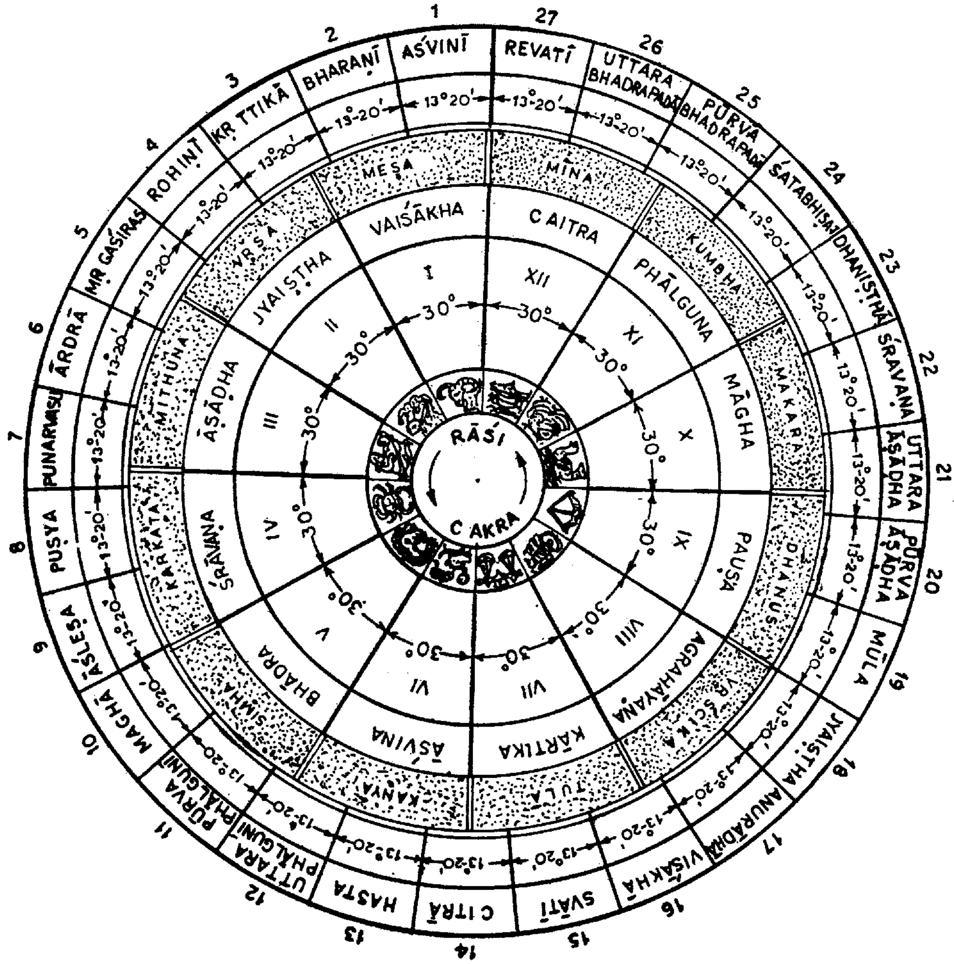


Fig. 9.2. Diagram showing the disposition of *rāśis, nakṣatras,* and solar months in the zodiac circle, and interrelation between these

In the Indian calendar there is a permanent relationship between the solar months, *rāśi* divisions, and *nakṣatra* divisions, and Fig. 2 below illustrates this relation.

It has been mentioned that the length of *nirayana* solar month is the time period measured from the moment the Sun enters the concerned *rāśi* (*saṃkrānti* of that *rāśi*) to the moment if enters the next *rāśi* which is the true time taken by the Sun to traverse the entire *rāśi*. This exact period of time is used for determining the lunar months which are named after solar months in which the initial new-moon of the lunar month occurs, and consequently also for determining the intercalary or mala months. But the *saṃkrānti* or ingress of the Sun into different *rāśis* may take place at any time in day or night, but the civil day begins from sunrise and, therefore, some rules are to be followed to determine the day from which the civil month is to start. Unfortunately no uniform rule or convention is followed for this purpose, and four different conventions have got established broadly in four different regions which often cause non-uniformity in the starting day of the same month in the same year in different regions, and in the length of the same month in succeeding years in the the same region. The conventions followed are described below:[32]

(a) *The Orissa Rule*

In Orissa the solar months for civil purpose begin on the same day (sunrise to next sunrise) as the saṃkrānti, irrespective of whether it takes place before or after midnight.

(b) *The Tamil Rule*

The rule followed by Tamil *pañcāṅgs* is that when a *saṃkrānti* takes place before sunset, the month begins on the same day, while if it takes place after sunset the month begins on the following day.

(c) *The Malayali Rule*

The rule followed by Malayāli *pañcāṅga* of Kerala is that, if the *saṃkrānti* takes place before *aparāhṇa*, that is, 3/5 of the duration of the day, which is reckoned as the time-period from sunrise to the following sunset, and this works out as 1-12 P.M. taking sunrise at 6 A.M., and sunset at 6 P.M., the month begins on the same day, otherwise it begins on the next day.

(d) *The Bengal Rule*

This rule is complicated compared to other rules. When a *saṃkrānti* takes place between sunrise and midnight of a civil day, the solar month begins on the following day; and when it occurs after midnight the month begins on the next following day, i.e. on the third day. This is the general rule, but if the *saṃkrānti* occurs in the period between 24 minutes (one *ghaṭikā*) before midnight to 24 minutes (one *ghaṭikā*) after midnight, then the duration of the *tithi* current at sunrise requires to be considered. If the *tithi* at sunrise extends upto the moment of *saṃkrānti*, the month begins on the next day; if the *tithi* ends before *saṃkrānti*, the month begins on the next following day, that is, the third day. But in case of Karkaṭa and Makara *saṃkrāntis*, the criterion of the *tithi* is not to be considered. If the Karkaṭa *saṃkrānti* falls in the above period of 48 minutes about the midnight, the month begins on the next day, and if Makara *saṃkrānti* falls in that period, the month begins on the third day.

The length of the sidereal year as given in the Modern or Current *Sūrya-siddhānta* is 365.258 756 days as against the modern or correct value of 365.256 349 when expressed in mean solar days or 365.256 363 in ephemeris days. *Sūrya-siddhānta* year is in excess over the modern value in mean solar days by 0.002407 days or by 3^m 28^s. Further, though *Sūrya-siddhānta* astronomers knew that the Sun's motion was not uniform, and it moves around the Earth in a circle with the Earth not being at its centre but at a small distance away from it, that is, the orbit is an eccentric circle or an epicycle, they did not know the correct value of the slow rotation of the apse line of the orbit. Their estimate of this motion was 11″ per century while the modern value is 11″.62 per year in the positive direction. As the equinoxes are now regressing at the rate of 50″.27 per year, the total change of the position of the apse line in relation to the line joining the equinoxes or solistices works out to about 1°.72 per century. Also the ellipticity of the Earth's orbit is not constant but is slowly decreasing, making it more circular. Hence the length of the *nirayana* months is slowly changing, but according to *Sūrya-siddhānta* the change will be very little and can be neglected. The Table 9.13 shows the difference between the length of months calculated as per *Sūrya-siddhānta,* and modern values for the year 1901 Śaka (A.D. 1979-80).

Table 9.13.[33] *Showing the lengths of nirayana* solar months according to Sūrya-siddhānta and as per modern value*

	Name of months along with *rāśis*	According to *Sūrya-siddhānta*			As per modern value (1901 Śaka) (1979—80 A.D.)		
		d	h	m	d	h	m
1.	Vaiśākha (Meṣa)	30	22	40	30	20	56
2.	Jyaiṣṭha (Vṛṣa)	31	10	14	31	6	39
3.	Āṣāḍha (Mithuna)	31	15	25	31	10	46
4.	Śrāvaṇa (Karkaṭa)	31	11	10	31	8	31
5.	Bhādra (Siṃha)	31	0	8	30	23	54
6.	Āśvina (Kanyā)	30	10	16	30	11	55
7.	Kārtika (Tulā)	29	21	10	29	23	46
8.	Agrahāyaṇa (Vṛścika) (or Margasīrṣa)	29	11	38	29	14	38
9.	Pauṣa (Dhanus)	29	7	42	29	10	42
10.	Māgha (Makara)	29	10	59	29	12	59
11.	Phālguna (Kumbha)	29	20	2	29	20	53
12.	Caitra (Mīna)	30	8	50	30	8	30
	Total	365	6	13	365	6	9

* The initial point of the *nirayana* zodiac has been taken to be the point in the ecliptic opposite the star Citrā (α Virginis)—the *ayaṇāṃśa* of this point on the 1st of solar Vaiśākha of 1901 Śaka being 23°34′.

LUNAR MONTH AND LUNAR YEAR

Lunar month and lunar year are very important items of *pañcāṅga* or the Indian calendric system. The lunar calendar in this system is not purely lunar in character line the Muslim Hejira calendar but it is tied with the solar calendar, and hence it is known as 'luni-solar' calendar.

The lunar month is measured either by the period covered from one new-moon to the next, or from one full-moon to the next one. The former month is called as *amānta* and also *mukhya māna,* and the latter as *Pūrṇimānta* and also *gauṇa māna.* As mentioned, the lunar months are named after the solar months where the initial new-moon of the *amānta* lunar month occurs, and for this purpose the solar month is reckoned to be the period of time between the exact moment of one *saṃkrānti* to the next. For example, if a new-moon (ending moment of *amāvasyā* which is the same as the beginning moment of *śukla pratipada*) falls in the solar month of Māgha, the *amānta* lunar month commencing from this new moon is also known as Māgha. Similarly the *amānta* lunar month commencing from the new-moon falling in the solar Phālguna, will be known as Phālguna. In the case of *pūrṇimānta* lunar calendar, the months of this calendar commence from the ending moment of *pūrṇimā* taking place of fortnight earlier than the initial new-moon from which the *amānta* month of the same name commences and ends in the middle of that *amānta* month. It may be interesting to note while nearly the whole of the *amānta* lunar month may sometimes fall outside the solar month with which it is linked and after which it is named, the *pūrṇimānta* month will always cover at least half of the above solar month. The *kṛṣṇa pakṣa* half of the lunar month is also called *vādi,* and the *śukla pakṣa* half as *sudi.* The Fig. 9.3. below shows the relation between the *amānta* and *pūrṇimānta* months of the lunar calendar.

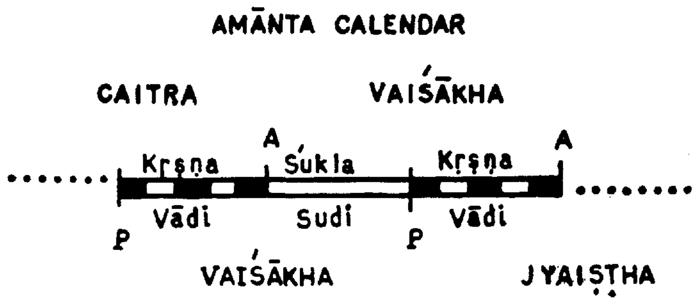


Fig. 9.3 *Pūrṇimauta* Calendar

Relantionship between Amānta and Purṅimānta months

A = Ending moment of *amāvasyā* or new-moon

P = Ending moment of *pūrṇimā* or full-moon

The *amānta* calendar is followed for all purposes, namely calendric (counting the days of the months), fixing the days of the festivals, and for other religious and

social purposes, in the states of Maharashtra, Karnataka, and Andhra, and the year of this calendar commences from Caitra *śukla pratipada*. In Gujarat also the *amānta* calendar is followed but the year starts after the Diwali new-moon, that is, from Kārtika *śukla pratipada* and is called as Kārtikādi calendar. In Kutch and some parts of Saurashtra, the *amānta* lunar months commence from Āṣāḍha *śukla pratipada* and is called, as Āṣāḍhādi calendar. The *amānta* lunar calendar is also followed for fixing the days of festivals and other religious purposes in the states of Tripura, Assam, Bengal, Tamil Nadu and Kerala where for dating purpose the solar calendar is used. The *pūrṃiānta* calendar on the other hand is used for all purposes in Bihar, Uttar Pradesh, Madhya Pradesh, Rajasthan, Haryana, and Kashmir. In Orissa and the Punjab where the solar calendar is in vogue, the lunar calendar followed is *pūrṇimānta*. It may be mentioned that the dates fixed for festivals are generally the same as per both the calendars.

A peculiar and some what perplexing feature of the *pūrṇimānta* calendar is that the first month of the year which is Caitra and the new year, do not start at the same time. The month of Caitra of this calendar starts, as usual, from the full-moon occurring a fortnight earlier than the new-moon from which *amānta* Caitra and *amānta* new year starts, but the year of the *pūrṇimānta* calendar starts at the same time as that of the *amānta* calendar. This means that the year of the *pūrṇimānta* calendar starts in the middle of its first month, Caitra, resulting in the counting of first half of Caitra, which is *vādi or kṛṣṇa* Caitra as a part of the previous year, and the latter half of Caitra, which is *sudi* or *śukla* Caitra as a part of the next year, which is the new year.

Mala Month and Kshaya month in the Lunar Calendar

The mean value of the synodic lunar month in mean solar days is equal to 29.530 59 days (29 days 12 hours 44.5 minutes) and hence the length of the lunar year comprising of twelve lunar months total 354.367 08 days (354 days 8 hours 48.6 minutes). The mean length of the sidereal *(nirayana)* solar year in mean solar days is equal to 365.256 349 days (365 days 6 hours 9.14 minutes). Hence the lunar year falls short of the solar year by 10.889 days. This difference will increase to one lunar month in 2.712 lunar years or in about 2 years and 8.5 months. This means that one additional lunar month called 'intercalary' month, or *mala* or *adhika* month is to be provided after every 2.7 lunar years to maintain the link of the lunar months with the corresponding solar months and hence with the seasons.

The requirement of intercalary lunar month can also be calculated as follows:
7 intercalary months in

$$
\begin{aligned}
\text{19 lunar years} &= (19 \times 12+7) \text{ lunar months}\\
&= 235 \times 29.530\ 59 \text{ days}\\
&= 6939.6886 \text{ days}\\
\text{19 solar sidereal years} &= 19 \times 365.256\ 35 \text{ days}\\
&= 6939.8706 \text{ days}
\end{aligned}
$$

These two lengths are nearly the same, the difference being only 0.182 days. This cycle is known as Metonic cycle, named after the Greek astronomer Meton. The Hebrew luni-solar calendar, which is used in Israeli, follows the above cycle, and the intercalary month is added in 3rd, 6th, 8th, 11th, 14th, 17th, and 19th year after the 5th month 'Shebat' and is kno n as Adar I, (Adar alef) while the normal month Adar is then called Adar II (Adar bet), and comes after the intercalary month.

The Indian luni-solar calendar, however, does not follow the above system of adding intercalary month on a fixed time schedule. The Indian astronomers devised an ingenious procedure based on the true motions on the Sun and the Moon, and Sewell and Dikshit in their book on "Indian Calendar" opines that this method was introduced at the time of the celebrated astronomer Śrīpati (A.D. 1039). It has been mentioned that the lunar months of the luni-solar calendar take this names after the solar months in which the *śukla pratipada* (initial new Moon) from which this lunar month commences, occurs. As the length of the lunar month is generally shorter than the solar months, it happens at some intervals of time that two new-moon occur in one solar month, and in that case two lunar months start from the same solar month, and so have the same name-designation. The first of these two lunar months is treated as an intercalary month, and is known as *mala* or *adhika* month, and no religious festivals and avoidable religious and social functions are permitted in this month. It will be observed that the *mala* month starts and ends in the same solar month while the normal lunar month starts in one solar month and ends in the next. This is sometimes expressed by saying that the *mala* lunar month has no *saṃkramana* while the normal lunar month has one *saṃkramaṇa*, that is, it crosses from one *rāśi* to the next. Under the above method the *adhika* or *mala* months recur at time intervals of 2 years 11 months, 2 years 10 months, and 2 years 4 months on a manner that average time interval works out to about 2.7 years, which is the calculated time interval for occurrence of such months.

It has been mentioned that *pūrṇimānta* month starts one *pakṣa* earlier than the *amānta* month of the same name but the *mala* month occurs in the same time-period of the year in both types of lunar calendar. To clarify this, let us take the year 1902 Śaka (A.D. 1980-81) when a *mala* lunar Jyaiṣṭha occurred and so there were two lunar Jyaiṣṭhas. In *amānta* calendar the first lunar Jyaiṣṭha was *mala* and this comprised of *śukla pakṣa* half followed by *kṛṣṇa pakṣa* half. The next Jyaiṣṭha which comprised again of the usual *kṛṣṇa* and *śukla pakṣas* was *śuddha*. In the *pūrṇimānta* calendar, as per rule, the month of Jyaiṣṭha started a *pakṣa* earlier as kṛṣṇa Jyaiṣṭha and this first half of the month was *śuddha*. The second half of the same first Jyaiṣṭha which was *śukla* Jyaiṣṭha and the first half of the second Jyaiṣṭha which was *kṛṣṇa* Jyaiṣṭha coincided with the time period of mala or adhika period of Jayiṣṭha of the amānta calendar, and were treated as *mala* or adhika Jyaiṣṭha in the *pūrṇimānta* calendar. The second half of the second Jyaiṣṭha of the *pūrṇimānta* calendar, which was *śukla* Jyaiṣṭha was treated as *śuddha* like the first half of the first Jyaiṣṭha which was *kṛṣṇa* Jyaiṣṭha. The above disposition of the *mala* or adhika months in two systems of lunar calendar is explained by Fig. 9.4.

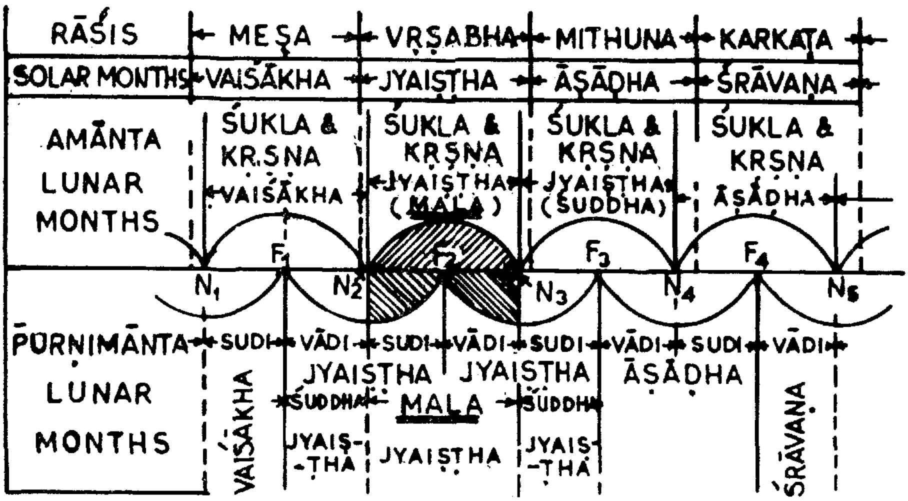


Fig. 9.4.

Note : N_1N_2, N_3,N_4 etc., and F_1, F_2, F_3, F_4 etc., indicate the time of occurrences of new moon and full moon respectively in the sidereal solar months Vaisākha, Jyaistha, Āsādha, etc. The curves joining N_1 and N_2 and N_3, N_3 and N_4, etc., and also curves joining F_1 and F_2, F_2 and F_3, F_3 and F_4, etc., indicate respectively amānta and purnimānta lunar months. As two new moons N_2 and N_3 occur in the same solar month Jyaistha, the amanta lunar month N_2—N_3 is an intercalary or mala month and is shown by hatched lines, and the corresponding mala month of the purnimānta calendar is shown beneath also marked by hatched lines.

It also sometimes happens, though at fairly long intervals of time, which may be as close as 19 years or as long as 141 years, and also on occasions at intervals of 46, 65, 76, and 122 years that no new moon (ending moment of amāvasyā) occurs in a solar month. In that case under the normal method of naming the lunar months, there will be no lunar month after the name of that solar month, that is, there will be a missing or decayed lunar month known as *kṣaya* month. It can also be expressed by saying that, when a lunar month has two *saṃkramaṇas*, a *kṣaya* month occurs. *Kṣaya* month is sometimes also called as *Ahaṃspati*.

When, however, a *kṣaya* month occurs in a lunar year, it is always accompanied by two *adhika* months, one occurring immediately or a few months before the *kṣaya* month and the other immediately or a few months after it. The situation that happens on the occurrence of a *kṣaya* month is that there are two *adhika* (extra) months and one missing month making a total of 13 lunar months in 12 solar months which is similar to the condition when a normal *adhika* or *mala* month occurs in a lunar year. But the difference is that in a *kṣaya*-month year, a lunar month is missing which causes a break in the seriality of the months. In actuality this can not be allowed to

happen as, apart from calendrical difficulties, religious festivals, ceremonies, rites, etc., pertaining to that missing month can not be left out. This problem of making compensation and adjustment for the missing month is dealt with in three different ways by three different schools which are prominent broadly in three different regions and this is described below.

Eastern region and a part of Northern region

Here the first *adhika* month occurring before the *kṣaya* month is treated as a *mala* or an intercalary month, and the second *adhika* month occurring after the *kṣaya* month is treated as a normal or *śuddha* month, and religious festivals are allowed to be performed in this month. Further this month is counted in a normal manner in continuation of the previous months so that there is no break in the seriality of the months of the year. This process provides all the normal number of twelve lunar months of the year, and the break caused by *kṣaya* month is thus repaired.

Northern-Western region and a part of Northern region

The procedure followed here is opposite to that mentioned above. Here the first *adhika* month, sometimes also called *saṃsarpa*, is treated as normal month for undertaking religious festivals, and the second *adhika* month occurring after the *kṣaya* month is treated as *mala* month. Here also like the previous procedure twelve lunar months are provided in the normal serial order, and the missing month is compensated by counting the first *adhika* month as a normal month. The difference of this procedure from the previous one will have the effect that the dates for performing the religious festivals and other religious activities which fall within the period between two *adhika* months, will be one month earlier in this case compared to the previous one.

Southern and Western Regions

Under the procedure followed in the above regions, both the *adhika* months are treated as *mala* months, and to make up for the missing month due to occurrence of *kṣaya* month, the lunar month which overlaps the solar month, that is, the lunar month which has two *saṃkramaṇas,* is treated as a dual *(jugma)* month comprising of two lunar months which are linked with the *rāśis* from which two *saṃkramaṇas,* that is, two crossings are made by the overlapping lunar month. This can be best explained by the actual *kṣaya* month that occurred in 1904 (A.D. 1982-83), which has been illustrated in Fig. 9.5. Here the lunar month which commenced from Dhanus *rāśi* (Pauṣa) ended in Kumbha *rāśi* (Māgha). This lunar month is treated as a dual month comprising of *Pauṣa* and Māgha, and the first half of the *tithi* of this dual month is considered to be the *tithi* of Pauṣa, and the second half to be that of Māgha. In this system dates of the festivals which occur in the period between the first *adhika* month and the first of the *jugma* month (included) will be the same as those for the eastern region, and the dates of festivals which come about in the period between second *jugma* month (included) and the second adhika month will be the same as those of the north-western region.

The occurrence of *kṣaya* month in the lunar calendar has been illustrated in Fig. Fig 9.5 by taking the example of the one that last occurred in 1904 Śaka (2039 Vikrama; 5083 Kali; or A.D. 1982-83). It shows the solar months from Āṣvina to Vaiśākha, (Vaiśākha being in 1905 Śaka), and the lunar months linked with these months which include two *adhika* months and a *kṣaya* month that occurred during this period. The figure is followed by Table 9.14 which illustrates the effect on the name designations of the lunar months on following three different procedures of the three different schools, and shows the difference that arises by following three different procedures.

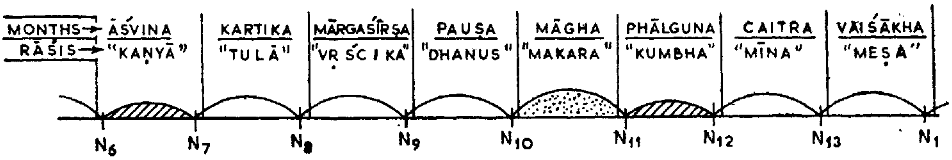


Fig. 9.5 Occurrence of two *adhika* months of Āśvina and Phālguna and the *kṣaya* month of Māgha in the lunar year of 1904 Śaka (1982-83 A.D.).

Note :

(a) N6, N7, N8 etc. are the positions of new-moons (ending moment of *amāvasyā*) in the sidereal solar months of Āśvina, Kārtika, etc.

(b) Lunar months N6-N7 and N11-N12 fall completely within the solar months of Āśvina (Kanyā *rāśi*) and Phālguna (Kumbha *enśi*), and are, therefore, respectively *adhika* Āsvina and *adhika* Phālguna. Again the lunar month N10-N11 completely overlaps or cross over the solar month Māgha (Makara *rāśi*), and therefore causes a *kṣaya* or a missing lunar month of Māgha.

Lagna or Ascendant

Lagna or ascendant is a very important item of information given in *pañcāṅga* which, is however, is outside its five limbs. Literally it means the point of the ecliptic which is attached with the eastern side of the horizon, or the point of the ecliptic which is just rising above the horizon. This information is vital for astrologers because *lagna* at the time of happening a particular event is taken to be the initial point for making astrological calculations. Generally *lagna* is indicated with reference to its position in the *rāśi* division; for example, when it is said that *lagna* of a particular event was 5°20′ of Karkaṭa *rāśi*, it means that the point of ecliptic which is 95° 20′ from the initial point was intersecting the eastern horizon. It may be mentioned that the *rāśis* or any point in the ecliptic are fixed points in the sky in relation to the stars and as such calculation of *lagna* timings is based on local sidereal time. Also as the ecliptic is inclined to the equator, the rising time of different *rāśi* divisions above the horizon, which is known as *lagnamāna* will be different at the same place, and again the time of rising of the beginning point of each *rāśi* division will be different for places with different latitudes.

Table 9.14 *Effect on the name designations of lunar months on following three different procedures of the different schools for treating the two adhika months and the kṣaya month that occurred in* 1904 *Śaka* (A.D. 1982-83).

Sl. No.	*Amānta* lunar months as per notation of diagram	Gregorian calendar dates from from new-moon to new-moon	Solar months where *amānta* lunar months start	Name of *amānta* lunar months as per different schools: South and west India *** (I)	East India & some eastern part of north north India (II)	North-west India & some western part of north India (III)
1	2	3	4	5	6	7
			1982			
1.	N6 to N7	17 Sep to 17 Oct	Āśvina	Āśvina *(adhika)*	Āśvina *(adhika)*	Āśvina* (saṃsarpa)ṣ i.e. *śuddha*
2.	N7 to N8	17 Pct to 15 Nov	Āśvina	Āśvina *(śuddha)*	Āśvina *(śuddha)*	Kārtika
3.	N8 to N9	15 Nov to 15 Dec	Kārtika	Kārtika	Kārtika	Mārgaśirṣa
			1983			
4.	N9 to N10	15 Dec to 14 Jan	Mārga-śīrṣa	Mārgaśīrṣa	Mārgaśīrṣa	Pauṣa
5.	N10 to N11	14 Jan to 13 Feb	Pauṣa ●	Pauṣa & Māgha *(kṣaya)*	Pauṣa *(kṣaya)*	Māgha *(kṣaya)*
6.	N11 to N12	13 Feb to 14 Mar	Phālguna	Phālguna *(adhika)*	Māgha**	Phālguna *(adhika)*
7.	N12 to N13	14 Mar to 13 Apr	Phālguna	Phālguna *(śuddha)*	Phālguna	Phālguna *(śuddha)*
8.	N13 to N1	13 Apr to 13 May	Caitra	Caitra	Caitra	Caitra

* 1st *adhika* month treated as a noɹmal month for religious festivals.

** 2nd *adhika* month treated as a normal month for religious festivals.

*** Kerala generally follows the North-Western Indian School.

● This lunar month-period which covers completely one solar manth and thus have two Saṃkramaṇs is treated as a dual or jugma month, that is, it comprises two lunar months, Puṣa and Māghā.

Ahargaṇa

The events are recorded on the basis of the calendar that is in force in the country at that time. But as it happens the mode counting the days by calendars have changed from time to time, and also intercalation of days or months introduced in the calendar to keep it corrected to its annual motion and to the seasons, more specially in the case of lunar calendar, make it difficult, and sometimes impossible, to find the correct day in relation to the present-day, when a particular event has happened. Also for comparing astronomical observations, it is imperative to know the exact time gap between the two events. This problem is tackled by the method of counting continuously without any break the successive days from an arbitrarily fixed epoch of very distant past, and of numbering the days consecutively, assigning each day a number which distinguishes it from other days. This system is named as *ahargaṇa*, literally meaning 'count of days.'

Āryabhaṭa I was the first astronomer in the world to conceive the brilliant idea of counting in a continuous manner the days without the involvement of months and years which varies from one calendar to another, and designating each day by a number. Āryabhaṭa however, calculated *ahargaṇas* by taking the beginning of Mahāyuga as the epoch, that is, as the zero day. But this practice involved very large numbers and was found to be cumbersome and hence later astronomers counted *ahargaṇa* from the beginning of Kali era, which was a much nearer epoch that commenced from the midnight of 17-18 February, 3102 B.C. *Ahargaṇa* day number is assigned on the basis of the number of mean solar days that have elapsed at midnight time at Ujjayin, from the Kali era epoch.

In the modern astronomy, like *ahargaṇa*, Julian day number is used which was introduced by a French scholar, Joseph Scaliger, in A.D. 1582 with the starting epoch time fixed at Greenwhich mean noon of 1st January, 4713 B.C. It will be interesting to compare the Kali *ahargaṇa* day numbers with those of Julian day numbers for certain dates, and this has been done below :

Date	Julian days (elapsed at Greenwhich mean noon of the day)	Kali ahargṇaa elapsed at Ujjaini mean mid-night on the ending of the day)
17 Feb 3102 B.C.	588 465	—
1 Jan 1900	2 415 021	1 826 556
15 Aug 1947	2 432 413	1 843 948
1 Jan 1984	2 445 701[34]	1 857 236

If ahargaṇas for an earlier epoch and for a later epoch are known, then this difference of ahargaṇa can be made use of for finding the position of the planets from their given position at that earlier epoch and their daily mean motion by the simple method :

The mean position for the required epoch
= the mean position of the earlier epoch
+ daily mean motion × difference of *ahargaṇas* between the two epochs.

Festival Dates in the Indian Calendar

Most of the days of our festivals repeat themselves in accordance with the *tithis*, of our luni-solar calendar. There are a few festivals like Vaiśākhī, Makara Saṃkrānti etc. whose dates are fixed in accordance with the solar sidereal calendar, while a still fewer ones like Onām are calculated on the basis of *nakṣatra* day.

The *pūrṇimānta* lunar calendar, as mentioned earlier, starts from the full-moon, occurring one *pakṣa* (fortnight) earlier than that of the *amānta* lunar calendar which makes the *kṛṣṇa pakṣa* dates of the *pūrṇimānta* calendar differ from those of the *amānta.* But the festival dates as per both the calendars remain the same; and for this purpose the dates fixed as per the *amānta* calendar are taken to be the basis. Now the month of amānta lunar calendar can start from any day in the month of the nirayana solar calendar after which it is named, and as such a *tithi* of a lunar month may occur either in the same solar month or in the next, and as such it will oscillate up and down in relation to the days of the solar calendar, and consequently the dates of various festivals will also oscillate in the same manner within the two months of the nirayana solar calendar in which the *tithi* of the lunar month can occur. The range of oscillation will be clear from the undermentioned Table 9.15 which gives the dates of festivals of Holi Vijaya Dasami, and Diwali that occurred in the years 1972 to 1980[35] as per Gregorian calendar.

Table 9.15. *Oscillation of the dates of various festivals in relation to the solar calendar (dates shown are of Gregorian solar calendar).*

Sl. No.	Christian era	Holi (Phālgunī *pūrṇimā*)	Vijayā Daśamī or Dusserāh (Āśvinī Śukla Daśamī)	Diwali (Āśvinī *amāvasyā*	Occurrence of lunar *mala* or intercalary month
1.	1972	29 Feb	18 Oct	5 Nov	Vaiśākha (14 Apr to13 May)
2.	1973	16 Mar	7 Oct	25 Oct	
3.	1974	8 Mar	25 Oct	13 Nov	Bhādra (18 Aug to 15 Sep)
4.	1975	27 Mar	14 Oct	3 Nov	
5.	1976	16 Mar	2 Oct	22 Oct	
6.	1977	6 Mar	21 Oct	10 Nov	Śrāvaṇa (16 Jul to 14 Aug)
7.	1978	25 Mar	11 Oct	31 Oct	
8.	1979	14 Mar	1 Oct	20 Oct	
9.	1980	2 Mar	19 Oct	7 Nov	Jyaiṣṭha (14 May to 12 June)
Maximum difference in the number of days			27 days	25 days	24 days

CONFUSION IN THE DATE OF THE REGIONAL CALENDARS

In India both solar and lunar calendars are followed, and in these two types again there are differences which divide them further into different kinds. But the name of months of the variant solar and lunar calendars are the same, and this results in the position that a day having same ordinal number of the same month-name indicates different days of the year. This has been illustrated in the Table 9.16 by taking the example of 11th Śrāvaṇa, 1905 Śaka (2040 Vikram or 5084 Kali) and it shows how the same above day of the different regional calendars has different corresponding dates of the Gregorian Calendar, and causes considerable confusion.

Table 9.16. *Table showing various calendar dates of* 11 *Śrāvaṇa,* 1905 *Śaka according to a number of regional calendars*

Sl. No.	Regional Calendars	Corresponding Calendar Date
	Day : 11 Śrāvaṇa 1905 Śaka or 2040 Vikram	
1.	Solar calendar of Orissa & Punjab	26 July
2.	Solar calendar of Bengal, Assam and Tripura	
	(a) Modern School	27 July
	(b) *Sūrya-siddhānta* School	28 July
3.	Solar Calendar of Tamil Nadu & Kerala	27 July
4.	Sāyana solar national calendar introduced by the Government of India	2 August
5.	Luni-solar *pūrṇimānta* calendar followed in Bihar, U.P., Madhya Pradesh, Rajasthan, and North West India (11th day from the starting of Śrāvaṇa) (Vādi Śrāvaṇa in this case)	5 August
6.	Luni-solar *amānta* calendar followed in Gujarat, Maharashtra, Andhra and Mysore (11th day from the starting of Śrāvaṇa) (śukla Śrāvaṇa in this case)	19 August

INITIAL OR ZERO POINT OF THE INDIAN ZODIAC

From the earliest times, the Indian astronomers have been following *nirayana* system for indicating the position of the heavenly bodies, and for counting the years. In the early Vedic period as mentioned earlier, the star Kṛttikā (η Taurus) was taken to be the initial star or point of the *nakṣatra* zodiac through which the vernal equinoctial colure used to pass when the initial observations were made. Next reference of the initial point is found in *Vedāṅga Jyotiṣa* where it has been sta tedthat the year starts from Dhaniṣṭhā *nakṣatra* (β Delphini) where the Sun and the Moon were in conjunction at winter solstice day, and so the initial point started from that *nakṣatra*. Again

from a reference in *Aśvamedha Parva* of the *Mahābhārata* (Chapter 44.2) it has been mentioned that *nakṣatras* commence from Śravaṇa (α Aquilae), and the seasons from *śiśira*, which means that winter solstice colure used to pass through that nakṣatra, and the year commenced from it.[36]

The founder-astronomers of the *Sūrya-siddhānta* system found the initial point of the year and so also that of the zodiac circle, which was fixed earlier with reference to Śravaṇa *nakṣatra* through which then passed the winter solstitial colure. This has lost its meaning because the year was no longer beginning from winter solstice due to retrogression of that point. They decided to shift the year-beginning from the winter solstitial point to or near the vernal equinox which was generally followed in the Vedic times when the year started from Kṛttika nakṣatra.

There is, however, no indication in the modern *Sūrya-siddhānta* of a definite loeation of the initial point in the ecliptic; it can only be inferred from the analysis of the co-ordinates given for the *yogatārās* or identifying stars in Chapter VIII of the book. Burgess in his translation of *Sūrya-siddhānta*, and more recently M. N. Saha and N. C. Lahiri of the Calendar Reform Committee analyzed these co-ordinates, and found that there was not one initial point with which the co-ordinates could be linked, but broadly there were three with which some link-up was possible. It was inferred by Prof. Saha that apart from observation made in the initial stage, two more observations were made by later *Sūrya-siddhānta* astronomers with reference to the then vernal equinoctial points, and these observations got interpolated and found place in the text. The observations made seemed not to be very accurate from the data available, and also some of the co-ordinates given could not be properly linked with the stars. However, from the analysis made, it has been inferred that *Sūrya-siddhānta* astronomers successively took three initial points as follows :

(a) the point in the ecliptic opposite the star Citrā (α Virginis), that is, the point from which the longitude of Citrā is 180°8′;

(b) the point in the ecliptic located about a degree on the east of Revatī (ζ Piscium), that is, one degree east of the point at which the great circle secondary to the ecliptic passing through Revatī cuts the ecliptic;

(c) the point in the ecliptic in line with Revatī, that is, the point in the ecliptic formed by the cutting of the great circle secondary to the ecliptic that passes through Revatī.

The epochs when the vernal equinox was successively at the above three points were about A.D. 300, 500 and 570 and hence it has been presumed, that initial point was changed on two successive occasions. However, in Varāhamihira's *Sūrya-siddhānta* the position of the star Maghā (Regulus-α Leonis) is given at the 6th degree of the Maghā *nakṣatra* division, and that of Citrā in the middle of the Citrā *nakṣatra* division; this indicates that in Varāhamihira's *Sūrya-siddhānta* the initial point was taken to be the one in the ecliptic opposite the star Citrā (α-Virginis), and hence it is very likely that the founder astronomers of *Sūrya-siddhānta* also adopted it as the initial point.

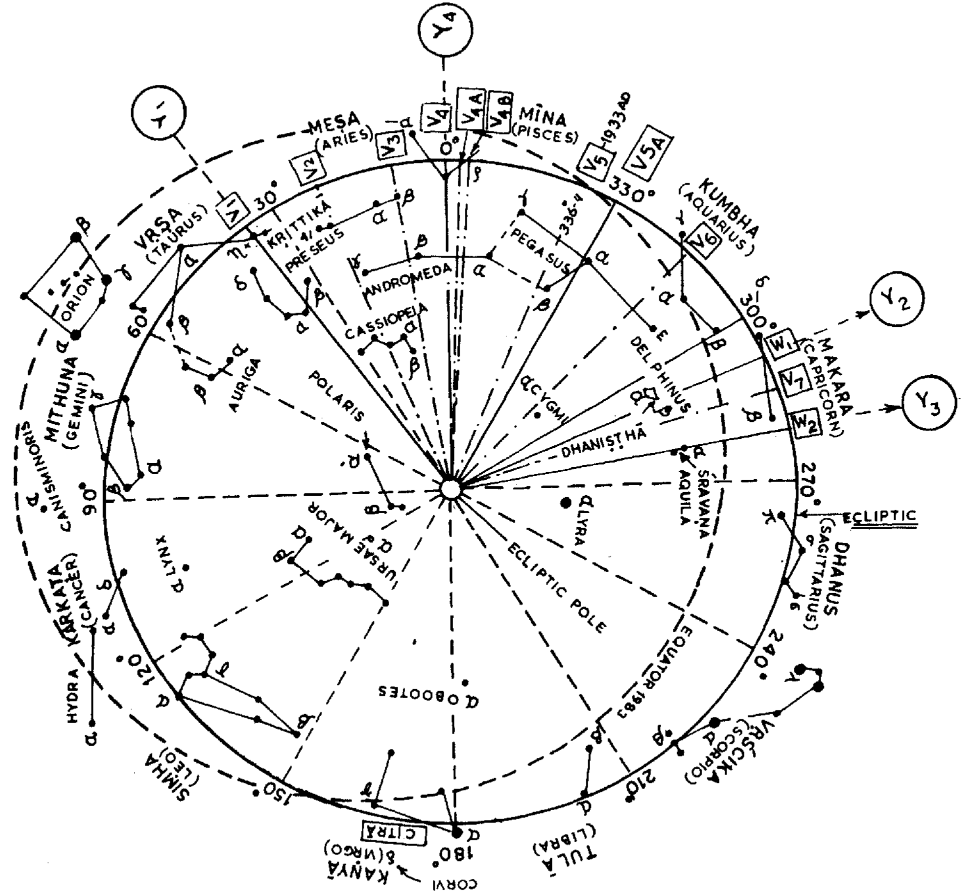


Fig. 9.6. Change in the positsons of Vernal Equinox and Winter Solstice throughout the ages.
(Year-Beginning of the Indian calendar in different epochs)

I. Positions of vernal equinox (V_1 to V_7) in different epochs

V_1 Early Vedic period : c. 2300 BC
V_2 Vedange Jyotiśa : c. 1400 BC
V_3 Mahabharata compilation : c. 400 BC
V_4 Zero point of Nirayana Zodiae 285 AD
V_{4A} Siddhanta Jyotisa : c. 500 AD
V_{4B} Later Surya Siddhanta : 570 AD
V_5 1983 AD
T_{5A} Beginning of Mina rasi : 2440 AD
V_6 Mid-Kumbha rasi : 3510 AD
V_7 Mid-Makara rasi : 5630 AD

II. Positions of winter solstice (W_1 to W_2) in different epoch

W_1 Beginning of Vedanga Jyotisa : c. 1400 BC
W_2 Mahabharata compilation : c. 400 BC

III. Year beginnings (Y_1 to Y_6) as reckoned in different epochs

Y_1 Early Vedic period : c. 2300 BC
Y_2 Vedanga Jyotisa : c. 1400 BC
Y_3 Mahabharata compilation : c. 400 BC
Y_4 Surya Siddhanta : 285 AD

The change in the positions of the vernal equinox and winter solstice at different ages and consequent change in the year-beginning of the Indian calendar at different epochs have been illustrated by Fig. 9.6.

At present, nearly all *pañcāṅga* makers, excepting a few, follow the 'Citrā' school, that is, they take the initial point to be opposite the star Citrā. It may be interesting to note that the longitude of the star Citrā from this fixed initial point which coincided with vernal equinox in A.D. 285 was then 180°0′, but it has now decreased to 179° 59′ due to proper motion of that star.

It is to be observed from the diagram that the Indian astronomers have all along been following the *nirayana* or the sidereal system for all their calculations, but they have been adjusting the initial point of the year to keep its months linked with the seasons when the equinoxes/solstices retrograded through nearly one *nakṣatra* division covering 13°20′ in the course of 900 years or so. It should be remembered that from the earliest times *nakṣatra* system of division of the zodiac was in use, and it is only during the *Sūrya-siddhāntic* period that *rāśi* system of dividing the zodiac was added having the same initial point as that of the *nakṣatra* system.

Interestingly no significant change in the starting point of the year has been made since the *Sūrya-siddhānta* system came into use about 1600 years back from now though earlier, as mentioned, almost every 900 years or so the change was effected when the equinoxes or solstices retrograded through one *nakṣatra* division due to precessional motion of the Earth. The main reasons for not effecting the change were probably as follows :—

(a) The *Sūrya-siddhānta* astronomers introduced the use of 12 *rāśis*, and linked each of the 12 solar months with a particular *rāśi* division, and began the year from the first point of the first *rāśi*, which is Meṣa, instead of linking the year with the *nakṣatra* divisions which was done earlier. It takes about 2100 years for the equinoxes to retrograde through one *rāśi* division measuring 30°, and hence it may be argued that perhaps for this reason no action has been taken so far. However, it may be mentioned that to keep the *nirayana* year adjusted to the vernal equinox which is taken to be the mid-point of the Indian spring season, it is better to change the year-beginning to the first point of the previous *rāśi* when the vernal equinox retrogrades to the middle of that *rāśi* rather than wait till it regresses to its beginning, because if the adjustment is done as suggested, the difference between the 1st day of the year and the vernal equinox day will vary from 15 days to 0 day in the course of 1050 years when the vernal equinox retrogrades through the first half of the *rāśi* from the beginning of which the year starts, and then again from 0 day to 15 days in the course of the next 1050 years when the equinox regresses further through the second half of the previous adjacent *rāśi*, and thus the mean variation becomes only 7½ days, as against the variation of 0 to 30 days, mean being 15 days, when the change in the year-beginning is made when the equinox has regressed

completely through one *rāśi* division in 2100 years. Viewing on the above basis, the change in the starting point of the year, which is now about 23°.6 degrees away from vernal equinox, may be deemed to be overdue.

(b) The *Sūrya-siddhānta* (chapter III, verses 9 to 12) has laid down the theory of trepidation of the equinoxes, and has mentioned that the amplitude of this precessional oscillation is 27°, and the period of one full oscillation is 7200 years, which incidentally, gives the rate of precession as 54″ per year. According to this theory no adjustment of the year-beginning is necessary. It is, however, believed that these verses are later interpolation because earlier astronomers like Āryabhaṭa, Varāhamihira, and Lalla (A.D. 748) do not mention anything about the precession. Any way, the theory of trepedation of the equinoxes has been mathematically proved to be wrong.

(c) After A.D. 1200 the Muslim invasion of North India disturbed greatly the peace of the country and consequently the scientific thinking and progress got arrested. Later the Muslims when they settled down as rulers imposed their non-seasonal purely lunar Hejira calendar, and the indigeneous Indian calendar assumed a subdued role. Again, during British regime which followed, the rulers introduced their Gregorian Calendar, and it occupied the frontal position by being used for all official and other related purposes, and the indigenous Indian calendar continued to lurk in the background due to lack of State support, and its use was confined to religious and socio-religious purposes. The dynamism of the astronomers as well as the popular will required for carrying out the necessary correction were, under the circumstances, lacking, and hence no serious thought was given to the requirement to keep the months of the year adjusted to the seasons.

Era

The era is an important factor in calendar keeping because by it the chronological reference to the past events as well as linking one event with the other can be made in an easy and systematic manner. Unfortunately in India the proper era system of recording data, that is, keeping a record of events in a continuous manner without a break was not in vogue in the early ages with the result that it is often difficult to place the events of that age chronologically in a correct manner for a proper study of ancient history, and other matters connected with chronology.

The earliest inscriptional evidence of the use of era is during the time of Emperor Asoka (273 to 227 B.C.) but the era used was regnal, that is, the number of years that have elapsed from the coronation of the king. The use of continuous eras for date-recording started in India from the time of Kuṣāṇa emperors and Śaka kings of Ujjain. This system of using an era for date-recording also came very late in ancient

nations like Egypt, Babylon, Assyria, Greece and Rome. Almost all the eras that have a very early beginning like the Kaliyuga era (—3101 A.D.), Christian era, etc were formulated at a later date by interpolation of the epochs from which the eras were taken to begin. The starting epochs of other recent eras normally are from coronation or some important event of a powerful king, or from the birth or death annivarsary of a great religious leader. Below are given the details of some of the important eras.

Kali Era

Of all the eras having ancient epochs, Kaliyuga or Kali era is the most important, and continues to be used throughout India though Śaka and Vikrama eras are used more extensively in their respective regions. This era is first mentioned by Āryabhaṭa I who said that when he was 23 years of age, 3600 years of Kaliyuga had elapsed, which is 421 Śaka or A.D. 499. It has been inferred that this era was in use before otherwise a statement like this could not have been made. But so far no record has been found of the earlier use of this era. There is a school who believes that Āryabhaṭa or some other ancient astronomer felt the necessity of an era that could normally cover the antiquity of our great civilization which could not otherwise be done by eras starting from a comparatively recent epochs like those of Śaka, Vikrama, Gupta etc, and so a new era was devised, but this is only a guess.

The beginning of Kaliyuga was taken to be the epoch when the Sun, Moon, and the planets were together in the beginning of the Meṣa *rāśi* which is the starting point of the Indian zodiac. The beginning of Kaliyuga era was the midnight at Ujjanī at the end of 17th February of 3102 B.C. according to ārdharātrikā system of Āryabhaṭa, as described in *Khaṇḍakhādyaka* of Brahmagupta. Again according to the *Āryabhaṭiya,* the Kaliyuga is said to have begun from the sunrise at Lankā on 18th Feb 3102 B.C. Lankā here means a point on the equator where the meridian circle passing through Ujjayinī cuts it. But by working out the positions of the Sun, the Moon, and the planets for the assumed time of the beginning of Kaliyuga, it is found that these were not together as presumed. The epoch was very likely fixed by making back calculations, and some error was made in calculation because perhaps the knowledge of astronomy was not so perfect as now to make correct calculations so many thousand years back. There is nothing unusual about it. The present Christian era, which is assumed to have begun from the date of birth of Jesus Christ, came into use at A.D. 532 on the basis of back calculation made by the Roman abbot Dionysius Exiguus, and it has now been found that the birth date of Christ then presumed is not correct. It is likely that Christ was born in 5 B.C. or a little earlier.[37]

What is important is that this Kali era is not regional, religious or sectarian in character, or connected with any king or war. It is completely secular and has an all-India significance being used universally though not as widely as the Śaka and Vikrama eras. The latter eras had more or less regional usage, the Śaka era in the south and the Vikrama in the north. The Kali era also serves well the original purpose of covering the facts of our ancient history in a normal manner without resorting to

the system of backward dating as done at present by using A.D. or B.C. against the year of the Christian era to specify the events of that period before the commencement of this era. The Kali era is used both for the solar and lunar calendar.

Vikrama Era

This era is widely used in most states of north-west India which follow *pūrṇimānta* lunar calendar, e.g. Bihar, Uttar Pradesh, Madhya Pradesh, Rajasthan, Haryana, Punjab, and north-west India. It is also used in Gujarat which, however, follows *amānta* lunar calendar but there this calendar starts from Diwali new-moon. The starting epoch of this era is 58 B.C. or —57 A.D. but its origin is not clearly known. The popular belief that Vikrama era was brought into use by King Vikramāditya of Ujjayinī in commemoration of his victory over Śaka or Scythian lords is not supported from inscriptions or historical record. This era was associated with Malāvas, and it was known as Malāva era for a very long time from the early 5th century. Before it was called as Kṛta era, but it is not known how this era came to be called by that name. Some scholars think that there might have been an illustrious Malava king of that name after whom the era was named. There is also an opinion that the era was founded by the Indo-Parthian chief Azes, and later adopted and its use made popular by the Malavas. But whatever may be the truth, this era had long and intimate association with Malavas, and the name Vikramāditya, it seems, was associated with it at a later date. It is not really known if a historical person of that title actually flourished at 58 B.C. or this title was adopted later by a Gupta emperor like Chandra Gupta II who adopted an existing era and renamed it after his title. Chandragupta II did defeat the śakas and this agrees with the popular belief about the foundation of this era, but he ruled about five centuries after the commencement date of this era, and hence the origin of Vikrama era is still obscure.[38] The use of this era was, however, made popular in north India by Pratihāra dynasty rulers as will be seen in what follows.

Śaka Era

This era starts from A.D. 78 and is very widely used as an era for both solar and lunar calendars. It is also known as śālivāhana śaka, śaka Samvat, and San śaka. Like the Vikrama era, the origin of this era is also not known with certainty. There are three different opinions on the origin of this era as described below:

(a) The most well known king in ancient India after Asoka is the Kuṣāṇa emperor, Kaṇiṣka, and it is believed that he started an era from the date of his accession which is now known as śaka era. However, the date of accession of Kaṇiṣka is not free from controversy. One opinion is that Kaṇiṣka used the old Śaka era omitting 200, the presumption being that there was a Śaka era which had an origin 200 years earlier than the present era, as mentioned in the next para. The date of Kaṇiṣka has been a very vexed question in Indian chronology, and no finality has been reached so far about the date of his accession.[39]

(b) The śakas who belonged to Central Asia attached the Parthian empire in 129 B.C. and established themselves by 123 B.C. and there is an opinion that they started an era from that date, and the present era is nothing but old śaka era with 200 omitted.

(c) Śaka astronomers known as Sākadvīpī brāhmaṇas were responsible to a great extent for the import of Graeco-Chaldean astronomy and horoscopic astrology in this country and the era used by them became prevalent, and this era came to be known as śaka era. The custom of using Śaka era for casting horoscopes continues even today.

Kollam Era

This era is prevalent in Malayalam countries (Kerala) and its origin again is obscure. This era is sometimes called as era of Paraśurāma, and the belief is that the Kollam era has come into being after omitting 'thousands' from this era. In Kerala, the solar year generally starts with the Sun entering Siṃha *rāśi,* and so the era starts from that time. The current year of the Kollam year corresponding to 1983 is 1159.

Buddha Nirvāna Era

This era, as the name implies, was founded after Lord Buddha by the Buddhists of Ceylon (Sri Lanka) from the date of his *parinirvāṇa,* which happened on Vaiśākha *pūrṇimā* day. The *nirvāṇa* year was taken by the Sri Lanka Buddhists as A.D. 544[40] and the era starts from that date. But the modern historians believe that the correct date of the death of Lord Buddha is 486B.C.[41] based on Cantonese record as well as well as on the testimony of the Greek writers. The Buddha *nirvāṇa* era year for 1905 śaka, (A.D. 1983-84) is given as 2527[42] which commences from Vaiśākha *pūrṇimā.* This era is not very much in use in India except by the Buddhists.

Mahāvira Nirvana Era

Like the Buddhists, the Jainas also started an era, known as Mahāvīra Nirvana era from the date of *nirvāṇa* of Mahāvira Jaina which was taken as 528 B.C. (—527 A.D.). Like Lord Buddha, there is a controversy on the correct date of death of Lord Mahāvīra. Many modern historians prefer 468 B.C.[43] to be this date relying on record left by Jaina monk Hema Candra. This era again is not widely used, it being confined to a few Jaina followers. Mahāvīra era for 1906-06 śaka (A.D. 1983-84) is 2510,[44] and the year commences from Kārtika śukla pratipada.

The Gupta Era

The era was established by the founder of the Gupta dynasty, Chandragupta I A.D. 319 to commemorate his coronation, and it was in vogue in the whole of northern India from Saurashtra to Bengal during the period of their supremacy (A.D. 319 to 550). Later when Harṣavardhana (A.D. 606-647) established his rule over north-India, the Harṣa era came into use replacing Gupta era, and it existed till the first quarter of the 9th century. Then when the Pratihāra dynastry led by Nāgabhaṭṭa

occupied Kanauj, they brought with them the Vikrama era which has been in use in Rajasthan from where they came, and this era became the era of north India. The popularity of this era was helped by its use by all Rajput dynasties who ruled north and north-west India, and it has stayed on as the leading era of north and north-west India.[45]

Tarikh Ilāhi Calendar and Ilāhi era of Emperor Akbar

Emperor Akbar found that the purely lunar Hejira calendar that was being used in all state matters, was not a very convenient one specially for land revenues purposes. This was because revenues were collected after the harvest, and so this was linked with the seasons, but the months of the lunar Hejira calendar moved through the seasons, and hence this calendar was inconvenient both for the point of view of the officials as well as the ryots. It is believed that he was advised by Todar Mall in charge of revenues, and by the Persian courtiers to adopt a solar calendar for state and other non-religious purposes so as to do away with the disadvantages inherent in the use of a purely lunar calendar. At that time Persia was culturally the most prominent one of all the Muslim countries, and did exercise a lot of influence on the cultural life of the Mughals and the learned elite, and there a solar calendar was in use for a long time for state purposes. Akbar decided to adopt a somewhat similar solar calendar for official use, and the new calendar that was introduced was named as *Tārikh Ilāhi*, meaning 'Divine Calendar', and the new era that was introduced was called the Ilāhi era, that is, 'Divine Era, which was also known as Akbar San.

It was thought appropriate to introduce the Divine Calendar from the year of Akbar's accession to the throne. Akbar was proclaimed as Emperor on 2nd Rabius sāni, 963 Hejira, or 14th February 1556 (Julian calendar), but *Tārikh Ilāhi* was not made to start from that date but from 27th day of Rabius sāni, 963 Hejira, or 10th March 1556 (Julian calendar)[46] or 21st March, 1556 when converted to Gregorian calendar date[47] because it was the vernal equinox day, the day from which the year of the new *Tārikh Ilāhi* calendar was devised to begin by following the same practice as it was then current with Persian solar calendar. The period of 25 days between the date of accession of Akbar and the commencement of the new calendar, was treated as 'decorative border to the days of the newly started year and as the preface of glory and conquest'.[48] The decision to introduce the Ilāhi solar era was taken on the 29th year (Hejira) of His Majesty's reign in 992 Hejira or A.D. 1584[49] with the year starting from 8 Rabiul awwal,[50] which was the vernal equinox day of 992 Hejira, but its commencement date was back dated to the spring equinox day of his year of accession, 963 Hejira, which was 10th March, 1556 (Julian), and was thus made the starting day of the Ilāhi era. The object of establishing this divine calendar and era, as given in the firman that was issued, was that the seasons of affairs and events might be known with ease and that no one should have an occasion for alteration, and also to liberate the businessmen from the perplexity of difficulties. The use of diverse eras (calendars) and their notorious beginnings were also among the causes for the institution of this new divine calendar and era.

Though Akbar followed the Persian practice of starting the year from vernal equinox day, he did not follow the month pattern of the Persian calendar which had 12 months of 30 days each with 5 separate intercalary days in normal years, and 6 days in leap years. Instead Akbar followed the Indian pattern (*Sūrya-siddhānta* pattern) of counting the lengths of the months on the basis of true solar months, that is, having the length of the 12 months equal to the time taken by the Sun to traverse the 12 concerned *rāśis*, but the initial point of the *rāśis* starting from Aries (Meṣa), was reckoned in this case, like the *sāyana* system, from the vernal equinox which had been chosen to be starting point of the Ilāhi calendar and which was also the initial point of the Persian zodiac signs. The length of the months being counted on the basis of true solar months varied from 29 to 32 days like the Indian solar calendar. So Akbar evolved the divine calendar by the blending of the Indian and the Persian systems.

There is, however, no clear record available as to what length was already adopted for each of the solar months, and what length was taken for the year. The little information that is available from writings and revenue records indicates that the length of the months, counted from the first month of the year, which was Farwardin, was of the pattern 31, 31, 32, 31, 31, 31, 30, 30, 29, 30 and 30.[51] The name of the months were made identical with the well-known names of the Persian calendar but were adorned by adding 'Ilāhi (divine) after their names, namely (1) Farwardin Ilāhi, (2) Ardibihisht Ilāhi, etc. Ilāhi calendar did not use the 7-day week cycle, and the days of the months were not distinguished by ordinal numbers, but each day had its own name which was the same as the then names of 30 days of the Persian month, namely (1) Ormuz, (2) Bahman, etc. The 31st and 32nd day of the month, which the Persian calendar did not have, were given special names, Ruz and Shub (day and night). The years were counted in duodenary cycles (12-year cycle), these years being named successively after each of the 12 months, namely, the first year was named as the year Farwardin Ilāhi, the second year was was the year of Arbidahisht Ilāhi, and so on.[52]

Tārikh Ilāhi calendar was used during the reign of Akbar and Jahangir, but after the death of Jahangir in A.D. 1627, Shāhjahān, who ascended the throne, reverted to the old lunar Hejira calendar, and from about A.D. 1630 the use of this sensible calendar for state and other purposes dwindled down though it continued to some extent for purposes of collection of revenues till about the end of reign of Aurangzeb.

Tārikh Ilāhi calendar and era gave rise to various calendars like Fasli, Amli, Vilāyati and Bengali San. The first three calendars have a very restricted use now, while the fourth one, namely Bengali calendar and San, continues to be widely used and has been discussed below.

Bengali Calendar and its Era (Bengali San)

When Akbar introduced the solar Tārikh Ilāhi calendar for state purposes, Bengal had already a solar calendar. The year of this calendar, however, commenced

from the solar month of Vaiśākha with the entry of the Sun to the 1st point of *nirayana* Meṣa *rāśi* as per *Sūrya-siddhānta* sidereal system and not from vernal equinox like the newly introduced *Tārikh Ilāhi* calendar, but this calendar was not interfered with.[53] The era, however, that was followed then in Bengal was Lakshmana Sena era which was used mainly in Mithila and other neighbouring areas for luni-solar calendar.[54] When Ilāhi solar era was introduced in A.D. 1584 with effect from A.D. 1556 Bengal also switched over to a new solar era, called as 'Bengali San'. This was done by adopting the commencement era-year of *Tārikh Ilāhi* to be also the commencement year of Bengali San. This means that the starting era year of Bengali San was 963 in A.D. 1556 like the *Tārikh Ilāhi*. Therefore, the Bengali San can be calculated by adding the number of solar years that have elapsed since 1556 with 963. The Bengali San year commences from mid-April (Meṣa *Saṃkrānti*) and hence the Bengali San year corresponding to A.D. 1983 (mid-April to December) will work out as (1983-1556) +963 = 1390. Incidentally the above calendric system is also followed in Tripura and Assam, but in the latter state the use of śaka era is also prevalent.

Other Eras

There are a number of other eras like Fasli, Āmli, Vilāyati, Saptarshi, Pārsi, Lakshmanasena, Chaitanya, Manipuri, Sivaji or Rajasaka, Magi, etc which have a restricted use either among some people of certain limited areas or among the religious sects which are reflected in the name of the eras. There were other eras like Chedi, Valabhi, Sahur-san, Harṣa, Nevar (old Nepali era), Calukya, Siṃha Samvat, etc. but these are no longer in use.

To show the interrelationship of the prominent eras that are widely used in the country and so also in *Pañcāṅgas*, table 9.17 has been prepared showing the starting epochs. This table includes the 'new' Śaka era, which was introduced recently by the Government with effect from 22 March 1957 along with the Saha Committee's *sāyana* calendar, named as 'national calendar'. It will be observed that apart from the dating aspect of the calendar, confusion exists in the counting of eras because the same eras like śaka and Vikrama start from different epochs.

JOVIAN YEAR OR BĀRHASPATYA VARṢA

There is a system of measuring the year on the basis of the time-period of Jupiter's motion through each *rāśi* which is nearly equal to the normal year, and this time-period is known as *Bārhaspatya Varṣa* or Jovian year. Jupiter makes a complete sidereal revolution when it traverses 12 *rāśis*, which comprise of 12 Jovian years, and a *yuga* of five such revolutions forms the 60-year cycle of Jupiter, and may be called the 60-year-cycle Jovian calendar.

According to *Sūrya-siddhānta* the sidereal period of Jupiter is 4332.32065 days (without *bīja* correction), and therefore by mean motion the length of the Jovian year is 361.026721 days. The length of the sidereal solar year as per *Sūrya-siddhānta* is 365.258756 days, and thus the Jovian year is very nearly equal to the solar year

and is less only by about 4.232 days. If the Jovian year and the solar year start at the same time, the Jovian year will constantly fall back and it will make a complete regression through 12 solar months in a period of $365.258756 \div 4.232035 = 86.308064$ Jovian years say 86.308 Jovian years. This means 86.308 Jovian years equal to the length of 85.308 sidereal solar years which may be simplified by saying

Table 9.17. *Relationship of the prominent eras used in Pañcāṅgas with the Christian era of Gregorian calendar*

Sl. No.	Name of the Era	Year beginning	Relationship with the Christian Era of Gregorian Calendar	Regions where used
Solar Eras				
1.	Kali	(a) Meṣa *Saṃkrānti* for solar Calendar	AD year+3101 from mid-April to December	General era followed by the solar and lunar calendars throughout India
		(b) Caitra S-1 for lunar calendar	AD year+3100 from Jan to Mid-April	
2.	Śaka (*Pañcāṅga* calendar)	Meṣa *Saṃkrānti*	AD year-78 from mid-April to Dec AD year-79 from Jan to mid-Apr	Tamil Nadu, Orissa and Assam, partly West Bengal along-with Bengali San
3.	Śaka (Government adopted *sāyana* calendar)	Day following vernal equinox day	AD year-78 from 22 Mar to Dec AD year-79 from Jan to 21 Mar	Government of India's sāyana calendar (National Calendar)
5.	Bengali San	Meṣa *Saṃkrānti*	AD year-593 from mid-April to Dec AD year-594 from Jan to mid-April	West Bengal, Tripura, and partly Assam
5.	Kollam	Siṃha *Saṃkrānti*	AD year-824 from mid-Aug to Dec AD year-825 from Jan to mid-Aug	Kerala
Luni-Solar Eras				
6.	Śālivāhana Śaka	*Amrāta* : Caitra S-1	AD year-78 from Mar/April to Dec AD year-79 from Jan to Mar/April	Maharashtra, Andhra Pradesh and Karnataka

Table 9.17.—*(Contd.)*

7. Vikrama Samvat (Caitrādi)	*Pūrṇimānta* : Caitra S-1	AD year+57 from Ma/April to Dec AD year+56 from Jan to Mar/April	UP, Bihar, MP, Rajasthan and North-West India
8. Vikrama Samvat (Kārtikādi)	*Amānta* : Kartika S-1	AD year+57 from Oct/Nov to Dec AD year+56 from Jan to Oct/Nov	Gujarat and some parts of Rajasthan Rajasthan
9. Vikrama Samvat (Āṣāḍhāi)	*Amānta* : Āṣāḍha S-1	AD year+57 from June/July to Dec AD year+56 from Jan to June/July	Kutch

86 Jovian years nearly equal 85 sidereal solar years. Therefore, if Jovian calendar is to be kept tied with the solar calendar, one Jovian year is to be expunged in every 85 solar years, and this expunged year is called *kṣaya* year. In actual practice, the interval between two *kṣaya* years is sometimes 85 and sometimes 86 years.

The 12-Jovian year cycle begins with the Jupiter's entry into Kumbha *rāśi* by mean motion, and in the 60-year cycle of the Jovian calendar this entry is marked by 1st (named as Prabhava), 13th, 25th, 37th, end 49th of that cycle. The type of 60-year cycle of Jovian years mentioned in the preceding paragraph is followed in north India. The use of Jovian calendar, however, is getting generally less prevalent there.

In the south which may be taken as the region south of Narmada, the Jovian years are counted in a normal manner in a regular succession, and no *kṣaya* year is made to occur. Further there are two types of Jovian years, solar and luni-solar, and the years of these two types start respectively from the ingress of the Sun into Meṣa *rāśi* like the normal solaı year, and from Caitra *śukla-pratipada* like the normal luni-solar calendar. So strictly speaking, ıhere is nothing Jovian in the south Indian calendar except for the adoption of the Jovian names for the years. This method of naming the years is sometimes used along with the normal calendric system. The south Indian practice of not expunging any year started from 827 Śaka or A.D. 905-06 and the result is that the south Indian Jovian Samvatsara year has fallen behind in comparison with the north-Indian Jovian year in the list of the cycle 60-years.

The list of the names of the Jovian years with their serial numbers of the 60-year Jovian cycle is given in Table 18. The name Samvatsara is usually added after the names of these years.

Reform of the Calendar Prepared on Surya-Siddhāntic Constants

As the time advanced, the knowledge of different branches of sciences also advanced. In the field of astronomy, its progress was greatly stimulated by the invention of refracting telescope by Galileo about 1610, reflecting telescope by

Table 9.18. *Serial list of the names of the Jovian years (Bārhaspatya Varsha)**

1. Prabhava	21. Sarvajit	41. Palavaṅga
2. Vibhava	22. Sarvadhārin	42. Kīlaka
3. Śukla	23. Virodhin	43. Saumaya
4. Pramoda	24. Vikṛta	44. Sādhāraṇa
5. Prajāpati	25. Khara	45. Virodhakṛt
6. Aṅgiras	26. Nandana	46. Paridhāvin
7. Śrīmukha	27. Vijaya	47. Pramādin
8. Bhāva	28. Jaya	48. Ānanda
9. Yuvan	29. Manmatha	49. Rākṣasa
10. Dhātrī	30. Durmukha	50. Anala (Nala)
11. Īśvara	31. Hemalamba	51. Piṅgala
12. Bahudhānya	32. Vilamba	52. Kālayukta
13. Pramāthin	33. Vikārin	53. Siddhārthin
14. Vikrama	34. Śarvari	54. Kaudra
15. Vṛṣa	35. Plava	55. Durmati
16. Citrabhānu	36. Subhakṛt	56. Dundubhi
17. Subhānu	37. Śobhana	57. Rudhirodgārin
18. Tārana	38. Krodhin	58. Raktākṣa
19. Pārthiva	39. Viśvāvasu	59. Krodhana
20. Vyaya	40. Parābhava	60. Kṣaya (Akṣaya)

a) *Indian Chronography* by Robert Sewell, (1212 Edition) 143, 145.
b) *Book of Indian Eras* by Alexander Cunnigham (Indian Reprint—1971), 25.
c) CRC Ceport Appendix 5E.

Newton about 1670, and achromatic lens for correcting the colour effect by Dollond in 1758, because these considerably enlarged the scope, and brought in accuracy in the observational study of the heavenly bodies, specially the Sun, the Moon, and the planets. All these progress happened mainly in Europe, but with the spread of education in this country, some of our elite became conversant with modern astronomy, and found out that some of the *Sūrya-siddhānta* constants on which our calendar and *pañcāṅga* are based have fallen out of date for the reason that at that time accurate observational facilities like telescope were not available, and our *pañcāṅga* pundits have not kept themselves abreast with the advanced knowledge of astronomy. They felt that necessary corrections should be carried out to some of our *Sūrya-siddhānta* constants and our *pañcāṅgas* and calendar corrected. This is an usual thing in all developing sciences, and as a matter of fact this system of keeping the basic constants up-to-date by making corrections from time to time as knowledge advanced was advocated by our later astronomers, and in fact is done now by modern astronomers.

The calendar reform movement gained strength in the latter half of 19th century, specially in the then presidencies of Bombay and Bengal. In Maharastra the most prominent exponent was Bal Gangadhar Tilak, the well known political figure and scholar. In 1851 Prof. K. L. Chatre of Poona took the initiative of publishing astronomical tables for the Moon and the planets based on the modern European authors like Delambre and others. In 1896 Sankar Balkrishna Dikshit published his book named *Bhāratiya Jyotiṣa Śāstra* in Marathi pointing our certain inaccuratices of *Sūrya-siddhānta* constant; Venkatesh Bapuji Ketkar composed in 1898 in Sanskrit tables called *Jyotirgaṇitam, Ketakī,* and *Vijayanti* based on correct modern values, and these are used even now by many almanac makers who are following modern values for making their calculations.

In Bengal, Shri Manmohan Banerjee, a zemindar, was one of the earliest persons to criticize the *tithi* timings given by the then traditional *pañcāṅgas*, the Gupta Press and Kalachand, and mentioned them as incorrect. Madhab Chandra Chatterjee, a civil engineer by profession, started a movement for calendar reforms in Bengal, and urged the use of modern tables for the preparation of *pañjikās*. In 1890, he commenced publishing in Bengali the *Biśuddha Siddhānta Pañjikā* showing the timings of *tithis, saṃkrāntis,* etc on the basis of modern values of the motion of the Sun and the Moon, and started using the correct length of the sidereal year. This *pañcāṅga* continues to be published, and is used by sizeable section of the people in Bengal, Tripura, Assam, and Manipur.

However, a very large number of inaccurate *pañcāṅgas* called *pañjikā* in Bengal, Assam, Tripura and Orissa continued to be published throughout India, and also a number of calendars differings from each other continued to be used in the country, causing a lot of confusion. The Government of India became increasingly aware of this confusion, and in November, 1952, appointed a Calendar Reform Committee to submit proposals for an accurate and uniform calendar for the whole of India. The Committee submitted its report at the end of 1954, and its recommendations for the introduction of a *sāyana* solar calendar for all-India use for general civil purposes and a new lunar calendar linked with a different *sāyana* solar calendar for religious purposes were accepted by the Government and introduced with effect from 22 March 1957.

10 ASTRONOMICAL INSTRUMENTS

R. N. Rai

Astronomy is an observational science. The position and movements of heavenly bodies have to be observed and recorded very accurately before a theory to explain their motions can be propounded. All theories have to be revised if their predictions are not in accordance with observational results. Also for many purposes the time since sun-rise has to be measured precisely. However, visual observations are not very accurate and it is necessary to devise instruments to ascertain the positions and motions of heavenly bodies and measure the duration of time.

Indian astronomers have devised a number of instruments and the most important of these is the armillary sphere. The earliest armillary spheres were very simple instruments. Ptolemy in his *Almagest* enumerates at least three. The simplest of all was the equinoctial armilla, a ring of bronze fixed in the plane of the equator. This was used to determine the time of the arrival of the equinoxes when the shadow of the upper half of the ring exactly covered the lower half. They had also the solstitial armilla which was a double ring, erected in the plane of the meridian with a rotating inner circle. This was used to measure the solar altitude. Probably Eratosthenes (c. 276-C.196 B.C.) used it for measuring the obliquity of the ecliptic. The complete armillary sphere with nine circles was built by the Alexandrian Greeks in the second century A.D.

However, the armillary sphere described by Bhāskara II and other Indian astronomers is a very elaborate affair. It consisted of a *bhagola* or the sphere of the fixed stars, a *khagola* or the sphere of the sky outside the *bhagola*. Then outside the *khogola*, there is a third sphere in which the circles forming both the spheres *khagola* and *bhagola* are mixed together. This is known as the *dṛggola*.

To construct the *bhagola*, a straight and cylindrical rod of any good quality wood is chosen as the *dhruva yaṣṭi* or polar axis. This is inserted in a small sphere which is held in the centre of the rod a little loosely so that the rod may move freely through it. The meridian circle is firmly fixed to the axis and the zenith and nadir points are chosen on it so that when the structure is suspended from the zenith point the axis will be pointing towards the north pole. Inside the meridian circle and attached to it are the circles of horizon, the equinoctial circle and the ecliptic. Every point of the horizon is at 90° from the zenith point. The equinoctial circle cuts the meridian circle in two points, one to the south of the zenith and one to the north of the nadir, the distance being equal to the latitude of the place. The ecliptic cuts the equinoctial at the first point of Aries, at the ascending node, and at the first point of Libra at the descending node. The ecliptic is marked with the twelve signs. It is to the north of the equinoctial by the obliquity of the ecliptic (24° according to Hindu astronomers)

at the first point of Cancer and by the same amount to the south of the equinoctial at the first point of Capricorn. In its annual motion, the Sun moves in the forward direction but the equinox point moves backward.

The planes of the orbits of the planets Moon, Mars etc. are inclined to the ecliptic and they should be so placed that the planetary orbits cut the ecliptic at the ascending and descending nodes and pass through the points three signs away from the ascending node, east and west, at a distance from the ecliptic, north and south, equal to the rectified latitude of the planet is obtained by multiplying the greatest mean latitude of the planet by the radius and dividing the product by the *śīghra karṇa*. Like the equinox point, the nodal points of the planets also move backwards and should be marked on the ecliptic by obtaining the position by calculation. Thus the position of the planetary orbits will be changing with time.

On either side of the equinoctial, three diurnal circles should be attached to the end points of the three signs beginning with Aries to the north and with Libra to the south, at distances equal to their respective declinations. They are all parallel to the celestial equator. The same circles considered in a contrary direction are the diurnal circles of the next three signs. The celestial equator and the six diurnal circles fixed parallel to it should be marked with 60 *ghaṭis*. The other circles should be marked with 360 divisions corresponding to 360 degrees.

One should also construct diurnal circles for the asterisms situated in the southern and northern hemispheres, of Abhijit, of the seven sages, of Agastya, of Brahma-Hṛdaya etc. The *bhagola* thus constructed should be firmly fixed to the polar axis.

The *khagola* is made up of the prime-vertical passing through the east and west points of the horizon and the zenith and nadir, the meridian circle passing through the north and south points of the horizon and the zenith and nadir, and the two vertical *koṇavṛtias* passing through the north-east and south-west and north-west and south-east points of the horizon. The horizon is placed transversely in the middle of them. Another circle known as *unmaṇḍala* is fixed to the horizon at the east and west points and passes through the north and south poles at a distance above and below the horizon equal to the latitude of the place. All these are marked with 360°.

The equinoctial, i.e., celestial equator (called *viṣuvadvṛtta* or *nāḍi-valaya*), marked with 60 *ghaṭis*, should be placed so as to pass through the east-west points of the horizon, and also to pass over the meridian at a point south from the zenith equal to the latitude of the place for which the sphere is constructed and north of the nadir at the same distance. Another smaller vertical circle is now fixed to the zenith and nadir points by nails so that it can revolve freely within them. This is the azimuth vertical circle and should be capable of being placed so as to cover the planet, wherever it may happen to be.

The *khagola* is now attached to two hallow cylinders in which the polar axis is inserted. Having thus separately fixed these two spheres, one attaches, beyond these,

by means of two other hollow cylinders, a third sphere in which the circles forming both the spheres *khagola* and *bhagola* are mixed together. For this reason this third sphere is called *dṛggola,* the double sphere. Thus the *bhagola* is firmly fixed to the polar axis which can be rotated without disturbing the two outer spheres.

To find the time since sun-rise and the *lagna* at that time the armillary sphere is set so that the east point is exactly towards the east and the horizon as level as water. The position of the Sun on the ecliptic is now obtained by calculation and the *bhagola* is rotated to bring this point of the ecliptic on the eastern horizon and a pin is fixed here to mark the position of the Sun. A pin is also fixed to mark the point of the equinoctial in the *bhagola* intersected by the eastern horozon, viz. east point. The *bhagola* is now rotated westward till the Sun throws its shadow on the centre of the Earth. The distance between the mark made on the equinoctial and the new eastern point of the horizon will represent the time from sun-rise. The point of the ecliptic now cut by the horizon will be the *lagna* or orient ecliptic point.

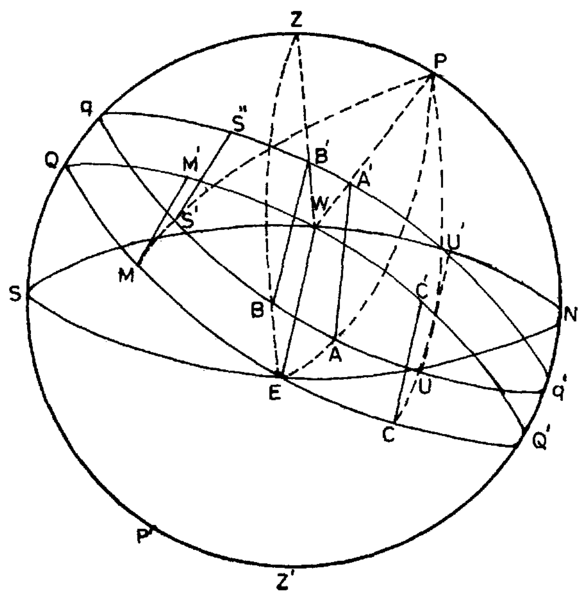


Fig. 10.1

Some of the circles are partly shown in fig. 10.1. NPZSZ'N is the meridian circle, NU'WSEUN is the horizon. EBZB'W the upper half the prime vertical and EAPA'W the upper half the *unmaṇḍala* or the six 0' clock circle. P and P' are the north and south poles respectively and Z and Z' the zenith and nadir respectively. QMEQ' WM'Q is the equinoctial and qBAUq'U'q is a diurnal circle. The Sun rises at the point U and UU' is the *udayāstasūtra.* S' is a position of the Sun at a certain time and PS'M and PUC are the *dhruva-protas* through S' and U respectively, meeting the equinoctial in the points M and C.

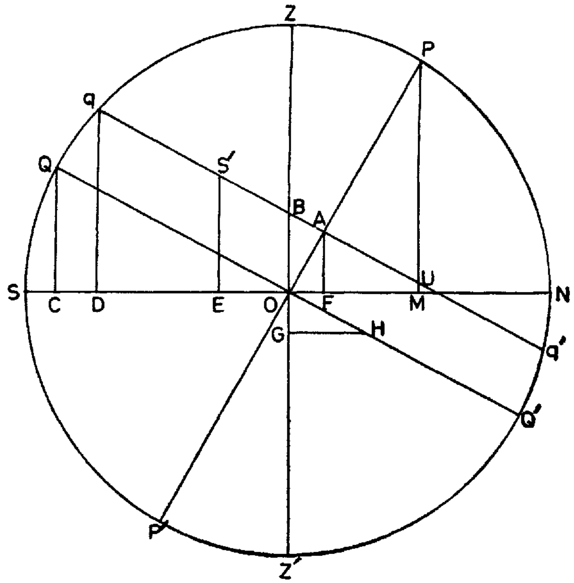


Fig. 10.2.

Fig. 10.2 shows the projection of the circles in fig. 10.1 on the meridian circle. U is the point where the Sun rises and S′ is its position at a certain time. OG is the gnomon and GH its mid-day shadow on the equinoctial day. This and the other perpendiculars will be needed in later discussions. Similarly fig. 10.3 is the projection of fig. 10.1 on the equinoctial and fig. 4 is its projection on the diurnal circle. These will also be needed in later discussion. In fig. 10.4 UU′ is the *udayāsta-Sūtra.*

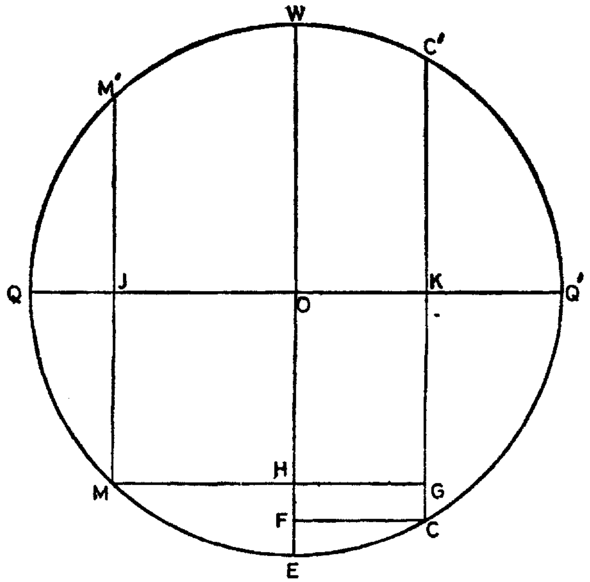


Fig. 10.3.

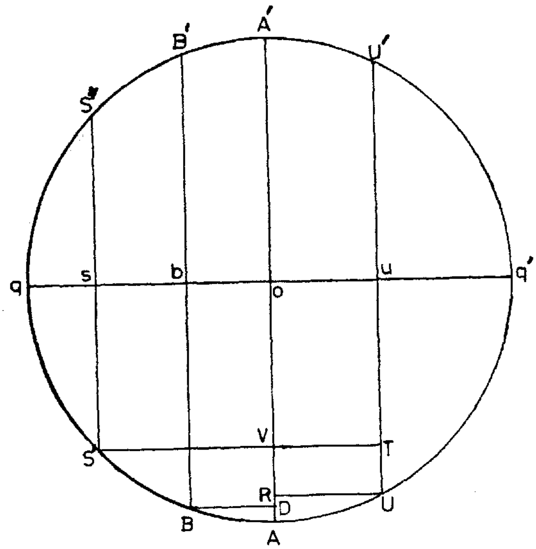


Fig. 10.4.

THE NĀḌĪVALAYA-YANTRA

The Nāḍivalaya—This instrument is shown in figure 10.5. It is a large circular wooden disc with an axis in the centre. It is divided into 60 *ghaṭikās* and also into 12 signs of the ecliptic which do not occupy equal arcs of the circumference but such variable arcs as correspond with the periods of their risings in the place of observation. The twelve periods thus marked are again subdivided into two *horās,* three *dreṣkāṇas,* into ninths, twelfths and thirtieths. These are called the *saḍvargas* or six classes. The signs, however, must be inscribed in the reverse order of the signs, that is first Aries, then Taurus to the West of Aries and so on.

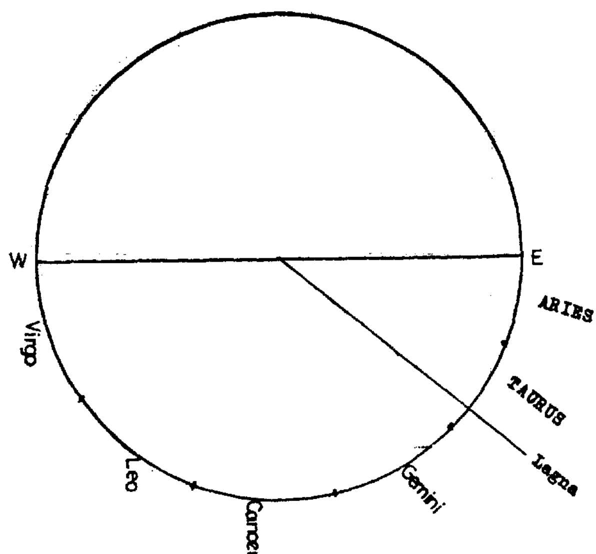


Fig. 10.5—*Nāḍivalaya.* The spaces on the circumference for the different signs are in proportion to their rising times at Delhi.

It is now placed in a plane parallel to the equinoctial so that the axis in the centre points towards the north pole. Now the longitude of the Sun in signs, degrees etc. for the sun-rise of the given days is obtained by calculation and that position is marked on the circle and the disc is rotated round the axis so that the shadow of the axis falls on the mark made for the position of the Sun at sun-rise. The disc now is fixed in position. In figure 10.5, the letters E and W have been put only to show that on the disc the sign of Taurus is to the west of the sign Aries, though in the sky Taurus is to the east of Aries. Now as the Sun rises, the shadow of the axis advances from the marks made for the point of the sun-rise to the nadir. The number of *ghaṭīs* will be seen between the point of sun-rise to the position of the shadow which will also indicate the *lagna* or the sign on the eastern horizon since the arcs occupied by the different signs on the circumference of the disc are in proportion to their rising times.

This is the situation when the Sun is in the northern hemisphere. The same disc, graduated in a similar fashion on its other side and with the axis protruding on the other side, can be used to determine the *lagna* and the time since sun-rise, when the Sun is in the southern hemisphere. In the alternative another disc, similarly graduated, with an axis perpendicular to its plane may be placed with its plane parallel to the equinoctial and may be used when the Sun is south of the equator.

In fixing the point of the ecliptic at sun-rise on the eastern horizon in the case of the armillary sphere and in adjusting the position of the *nāḍīvalaya* so that the shadow of the axis falls at the position of the Sun at sun-rise, one should take into account the precession of the equinoxes which should again be taken into account in determining the *lagna*.

A similar instrument has been described by Lalla and called by him the *bhagaṇa-yantra*.

The Pīṭha-Yantra and Chatra-Yantra :

The Chatra-Yantra and the Pitha-Yantra described respectively by Āryabhaṭa and by Brahmagupta and others are similar. But, unlike the Nāḍīvalaya, they are placed in a horizontal plane. They are made of metal or good wood and are circular in shape in which east-west and north-south directions have been marked and of which the circumference has been divided into 360°. In the centre, a staff is put equal to the radius of the circle. The instruments are to be put at eye-height. The distance of the end of the shadow of the staff at sun-rise from the west point is the Sun's *agrā*. This point is known as the setting point. Similarly the end of the Sun's *agrā* in the east is the rising point. From the setting point to the rising point, on the northern half of the diurnal circle lie the graduations of the degrees of time in these instruments. The degrees on the diurnal circle intervening between the end of the shadow and the setting point in the west, divided by six give the *nāḍīs* elapsed during the day. But this is not quite accurate.

KARTTARI-YANTRA

The Karttari-Tantra described by Brahmagupta consists of two semicircular plates. One of these is in the plane of the celestial equator and is its lower half. The other semicircular plate is in the meridian plane below the polar axis, the diameter of the latter being evidently along the polar axis. At the junction of the east-west line and the north-south line, (i.e. at the centre of the plates) a needle is fixed pointing towards the pole. From the shadow of the index on the equatorial plate, time from sun-rise can be determined.

It is evident that the equatorial plate can be rotated in its own plane in order that the shadow of the needle may fall at sun-rise on the plate whatever may be the sign in which the Sun is lying. In this respect it resembles one half of the Nāḍīvalaya of Bhāskara II.

The Karttari-Yantra described by Lalla and śrīpati is not actually this instrument at all since it consists of only one semi-circular plate fixed in the plane parallel to the celestial equator with the needle fixed at the centre and pointing towards the pole.

THE GOLA-YANTRA

The armillary sphere and the Nāḍīvalaya described so far will measure the time and indicate the *lagna* only after sun-rise on a day when the sky is clear. However, it is necessary to measure time during night time also and to determine the *lagna* at a particular instant. For this purpose, Hindu astronomers had devised other instruments. One of these was the automatic sphere which is described by by Āryabhaṭa thus :

"The sphere (Gola-Yantra) which is made of wood, perfectly spherical, uniformly dense all round but light (in weight) should be made to rotate keeping with time with the help of mercury, oil and water by the application of one's own intellect".

Its working has been described by the commentator Suryadeva as follows :—

"Having set up two pillars on the ground, one towards the south and the other towards the north, mount on them the ends of the iron needle (rod) (which forms the axis of rotation of the sphere). In the holes of the sphere, at the south and north poles, pour some oil, so that the sphere may rotate smoothly. Then, underneath the west point of the sphere dig a pit and put into it a cylindrical jar with a hole in the bottom and as deep as the circumference of the sphere. Fill it with water. Then having fixed a nail at the west point of the sphere, and having fastened one end of a string to it, carry the string downwards along the equator towards the east point, then

stretch it upwards and carry it to the west point (again), and then fasten to it a dry hollow gourd (appropriately) filled with mercury and place it on the surface of water inside the cylindrical jar underneath, which is already filled with water. Then open the hole at the bottom of the jar so that with the outflow of water, the water level inside the jar goes down. Consequently, the gourd which, due to the weight of the mercury within it, does not leave the water pulls the sphere westwards. The outflow of water should be manipulated in such a way that in 30 *ghaṭis* (=12 hours) half the water of the jar flows out and the sphere makes one-half of a rotation, and similarly, in the next 30 *ghaṭis* the entire water of the jar flows out, the gourd reaches the bottom of the jar and the sphere performs one complete rotation. This is how one should, *by using one's intellect, rotate the sphere keeping pace with time. (Translation due to Dr. K. S. Shukla and Dr. K. V. Sarma, Āryabhaṭīga of Āryabhaṭa.)*

This device is described by Lalla also. The amount of mercury put into the gourd should be chosen in such a way that the gourd may float in the water. However, the flow of the water cannot be uniform. When the cylindrical jar is full the pressure on its bottom will be high and the water will flow out more rapidly than when the jar is nearly empty. Thus the rotation of the sphere cannot be uniform.

A variant of this instrument has been described by Āryabhaṭa in his *Āryabhaṭa-siddhānta* which is now lost. In this a smooth cavity is constructed inside a pillar with a hole at the bottom. The whole length of the pillar is divided by the number of *ghaṭīs* taken by the water to flow out completely. This gives the measure of *aṅgula* which corresponds to one *ghaṭi*. The measure of a *ghaṭī* is the basis for the determination of the height of the pillar and of the length of the cord to be used in connection with the time-measuring instruments. A man or other animals are attached to the pillar to make the total height equal to sixty *aṅgulas* as determined above. A cylindrical rod the circumference of which is equal to one *aṅgula* is inserted through the ears of the animals and it is wrapped sixty times round the rod and its one end is attached to the dry gourd containing appropriate amount of mercury. The gourd is now placed inside the cavity of the pillar, water from which flows out through suitable holes in the animals. As an *aṅgula* of water now flows out in a *nāḍi*, the gourd within the pillar goes down by an *aṅgula*. The cord wrapped around the rod also goes down towards the hole underneath due to the pull of the gourd and the rod is rotated through one turn. At one extremity of the rod, protruding outside the instrument, another cord is suspended and the number of coils made by this cord on the rod will indicate the *nāḍis* elapsed.

Similar instruments are mentioned by other astronomers also. The non-uniformity in the flow of water out of the orifice with change in the amount of water inside the cavity occurs in this variation too. It should also be remembered that the duration of time from one sun-rise to the next is not the same for all solar days. It varies from day to day. The longest solar day occurs about December 22, and the shortest solar day about September 17, the difference between the longest and shortest days being about 51 seconds.

The Ghaṭī-Yantra

The Clepsydra or the Ghaṭī-Yantra seems to have been in use in India since very ancient times. It has been described in the *Vedānga Jyotiṣa, Divyāvadāna* the *Purāṇas* and *Kauṭilya's Arthaśātra* and by Āryabhaṭa and other astronomers. But the measure of the vessel and of the hole in its bottom through which the water flows is given differently by different authorities. According to *Divyāvadāna*, the volume of the vessel, which is in the form of the lower half of a spherical water-pot called *kalaśa*, is a *droṇa* of water; according to *Vedāṅga Jyotiṣa* it is a *droṇa* less three *kuḍavas* and is thus equal to 61/64 *droṇa*; and according to Kauṭilya and the *Purāṇas* it is one *āḍhaka*, i.e., 1/4th of *droṇa*. The size of the hole is not given in the *Vedāṅga Jyotiṣa*. According to *Divyāvadāna*, the hole was made by a pin, needle, wire or rod four *aṅgulas* or finger-breadths in length, which was drawn from a piece of gold which weighed one *suvarṇa*. But according to Kauṭilya and the *Purāṇas*, it was drawn from a piece of gold weighing four *māṣās*, i.e. one-fourth of a *suvarṇa*. Evidently one *suvarṇa* is equal to one *karṣa* as defined by Bhāskara II in *Līlāvatī*. Thus the size of the hole given by Kauṭilya and the *Purāṇas* is one-fourth the size of the hole given by *Dviyāvadāna* as their vessel is one-fourth the size of the latter vessel. But there is a slight difference in the size of the vessel prescribed by the *Vedāṅga Jyotiṣa* and that given in *Divyāvadāna*. Perhaps *Vedāṅga Jyotiṣa* gave a precise value for the size of the vessel while the other three were satisfied with a rough practical measure.

In the form described by the astronomers of the siddhānta period, the water does not flow out of the hemispherical vessel, but the vessel is floated in a large recepticle of water and water-flows into it through the hole and its sinks in one *ghaṭikā*. However, Varāhamihira has described both forms in the *Pañcasiddhāntikā*. According to Āryabhaṭa, the hemispherical bowl is to be manufactured of copper, 10 palas, in weight and six *aṅgulas* in height, and twelve *aṅgulas* in diameter at the top. At its bottom, the hole is to be made by a needle eight *aṅgulas* in length and one *pala* in weight. But Lalla says that the hole is to be bored by a needle of uniform circular cross-section and four *aṅgulas* in length made of 3½ *māṣās* of gold. This is the specification of śrīpati also. However, Bhāskara II says that it is very difficult to construct a vessel and make a hole in it which will sink exactly 60 times during day and night. Therefore one should divide 60 by the number of times the vessel sinks into the recepticle to get a measure of the clepsydra.

Any copper vessel with a hole at the bottom and made in such a way that it sinks in the recepticle 60 times in a day and night is called *Kapāla* by Āryabhaṭa and the *Sūrya-siddhānta*. But according to Varāhamihira, Kapāla-Yantra is another instrument which will be described later.

When the clespydra is used by the flow out of water method, the flow of water will decrease as the height of water in the vessel decreases. But since the area of cross-section of the vessel also decreases, the two could be adjusted so that equal decrease in height denotes equal time. Alternatively the clepsydra can be calibrated with the help of the Gola-Yantra. But when the water flows into the bowl, the pressure

difference between the water in the recepticle and that in the bowl supports the weight of the bowl. Thus the pressure difference will be more when the cross section is small, i.e. for the initial flow of water, than when the bowl is nearly full. So the instrument will have to be calibrated to give fractions of a *ghaṭikā*.

In Babylonia, a cylindrical vessel was used as a water-clock. From there the instrument was introduced to Egypt. The oldest specimen of an Egyptian water-clock dates from about 1400 B.C.

The Gnomon

The gnomon was perhaps the most versatile instrument with the Indian astronomers. It was used by all ancient nations for the measurement of time. Most probably it was invented by the Babylonians around 1750 B.C. But no word for gnomon occurs in Babylonian gnomon tables which have been preserved. Only the shadow is mentioned and measured. The gnomon was introduced in Egypt in about 1500 B.C. and later from Egypt to Greece. In the *Aitareya Brāhmaṇa* it has been said that the sun remains stationary at the summer solstice for 7 days. This must have been observed with the gnomon.

In ancient times the gnomon was probably no more than a stick stuck vertically in the ground, thus forming a rudimentary sun-dial, and was the first astronomical instrument. In early Greece and late dynastic Egypt, the gnomon rose like a slender obelisk from the centre of a graduated circular pavement. When the shadow of the pillar was at its shortest length on any day, the gnomon indicated midday. To obtain some idea of the time of the morning or afternoon, the observer noted the length and direction of the shadow.

An alternative shadow clock took the form of a portable L-shaped piece of wood which in use was laid on its back in the direction of the Sun. The shorter leg then served as a vertical gnomon and cast its shadow on graduations marked on the longer horizontal leg. In another type of sun-dial, called the *hemicycle* and said to have been introduced at Athens by Berosus, the shadow of a vertical gnomon fell on the inner surface of a hemisphere. The end of the shadow traced a curve, the position of which depended on the time of the year.

The gnomon was used for the measurement of time, the determination of the solstices, the equinoxes and of geographical latitudes. Knowing the height of the gnomon and the length of the shadow, one can calculate the Sun's meridian zenith distance which at the time of the equinoxes is equal to the latitude of the place of observation. Using this method, Eratosthenes had available the approximate latitudes of Alexandria, Syene, Carthage, Rhodes and Byzantium.

The gnomon was generally of a standard length. But for greater accuracy one could use a very tall gnomon. By means of a gnomon some 180 feet high, Ulugh Beg and his assistants determined the latitude of Samarqand and the obliquity of the ecliptic with great precision. In India the standard length for the gnomon was 12 *aṅgulas*. But some authors say that it can be as high as 96 *aṅgulas* or any multiple of 12. Bhāskara I in some questions takes the height of the gnomon to be 30 *aṅgulas* and 15

aṅgulas. Whatever the height of the gnomon, it is generally divided into 12 divisions, each division being called an *aṅgula* or finger. According to al-Bīrunī, it may be divided into 60 divisions called 'parts' or into seven divisions called 'feet'.

Āryabhaṭa describes three kinds of gnomons. The first is uniformly circular and two *aṅgulas* in diameter at the bottom. This kind has been mentioned also by Lalla and Śrīpati. The second kind is one having equal circles at the top and bottom. This has been described by Bhāskara II who says that it should be made of ivory instead of strong timber. The third kind was, according to the trranslation of Prof. K. S. Shukla, 'pointed at the top, and massive at the bottom (i.e. conical in shape); (associated with its is) another true gnomon of the same height, mounted vertically on two (horizontal) nails fixed (to the previous gnomon) at the top and bottom thereof." It is not very clear what Āryabhaṭa means by this kind of gnomon. Perhaps in this the associated gnomon was of the kind envisaged by al-Bīrunī which casts the shadow on a vertical surface, e.g. when the gnomon is fixed perpendicular to a wall. The shadow cast on the ground by the gnomon fixed verticaly is called *umbra rects* while the shadow directed towards the ground is called *umbra versa*.

The first use of the gnomon in India appears to be to fix the cardinal points. For this purpose the gnomon is placed on a plastered surface, made level with a water-level, and a circle of any desired size is drawn on the surface with its centre at the gnomon. The two points where the shadow touches the circle in the forenoon and afternoon are marked and with these points as centres, a fish figure is drawn. Then the line passing through the mouth and the tail of the fish will be the north-south line.

This method of finding the north-south line would have been correct if the declination of the Sun remains unaltered between the forenoon and the afternoon positions. On account of the motion of the Sun on the ecliptic, the declination changes and the line joining the forenoon and afternoon points is not in the east-west direction.

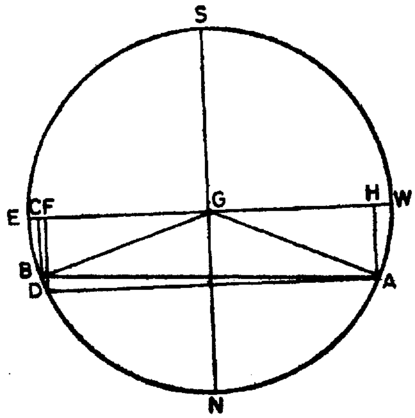


Fig. 10.6.

In fig. 10.6, G is the foot of the gnomon. ENWS is the circle drawn with G as the cet.e, A is the point where the shadow touches the circle in the forenoon and B is the point where the shadow touches the circle in the afternoon. The distances of A and B from the east-west line are not equal and the line AB is not in the east-west direction. Now Burgess, in his notes on verse 7 of chapter III of *Sūrya-siddhānta* has proved that

$$\frac{\textit{karṇa vṛttāgrā}}{\text{hypotenuse of the shadow}} = \frac{\textit{agrajyā}}{\textit{trijyā}}$$, where *karṇa-vṛttāgrā* is the distance of the end point of the shadow from the equinoctial shadow line. Now from fig. 10.2.

$$\textit{agrajyā} = \mathrm{OU} = \frac{\mathrm{OA}}{\cos\phi} = \frac{R\sin\delta}{\cos\phi}$$

$$\therefore\ \textit{karṇa-vṛttāgrā} = \mathrm{H}\ \frac{R\sin\delta}{R\cos\phi} = \frac{H\,\mathrm{Sin}\ \delta,}{\cos\phi}$$, where $H =$ hypotenuse.

If the Sun is in the southern hemisphere, *bhuja*=*karṇa-vṛttāgrā*+equinoctial shadow, and if the Sun is in the northern hemisphere and north of the prime vertical, *bhuja*=*karṇa-vṛttāgrā*, if the Sun is south of the prime vertical which is the case in fig. 10.6.

Assuming that δ is positive when it is north, *bhuja* is positive when the Sun is north of the prime-vertical and the equinoctial shadow is always positive, the second equation holds. Taking sign into consideration, the others have also the same form.

$$\triangle \textit{bhuja} = \triangle\ \textit{karṇa-vṛttāgrā}, \text{ for figs 10.2 and 10.6,}$$

$$= \triangle\ \frac{\sin\delta}{\cos\phi},$$

since the equinoctial shadow remains constant.
Hence in fig. 10.6,

$$BC - AH = -\ \frac{H}{\cos\phi}\ (\sin\ \delta_2 - \sin\ \delta_1),$$ since the *bhuja* in fig. 10.6 has a negative sign. Since δ_1 and δ_2 can be calculated, we can obtain the correct value of the *bhuja DF* by applying this correction. The fish figures drawn from *D* and *A* as centres will give the correct north-south and east-west directions. By a repetition of the same process, the intermediate points of direction can be obtained.

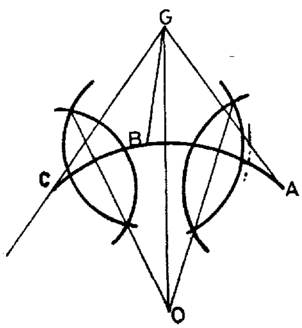


Fig. 10.7.

Varāhamihira, Brahmagupta, Bhāskara I, Vaṭeśvara and Śrīpati have all described another method for drawing the north-south meridian line by taking three points A, B and C in the path of the shadow of the gnomon G as illustrated in fig. 10.7. Here two fish figures are drawn by taking the points (A, B) and (B, C). The two straight lines drawn through the mouth and tail of the fish figures meet at the point 0. Then GO is the meridian line. Here two assumptions are made. One is that the declination of the Sun does not change during the day. The second is that the path of the end point of the shadow is a circle. None of these is correct, the path being a hyperbola. Bhāskara II therefore, criticizes this method of determining the east-west and north-south lines.

We can obtain the time elapsed since sun-rise or the time to elapse before sunset with the help of the gnomon and its shadow. Bhāskara I says:

"Multiply the R sine of the Sun's altitude derived from the given shadow (of the gnomon) by the radius and divide (the product) by (the R sine of) the colatitude. Then substract the minutes of the earth-sine from or add them to the resulting quantity according as the sun is in the six signs beginning with Aries or in the southern hemisphere. Multiply the resulting quantity by the radius and divide (the product) by the day-radius. To the corresponding arc apply the ascensional difference contrarily to the above; thus is obtained the number of *asus* (elapsed since sun-rise in the forenoon or to elapse before sunset in the forenoon)".

In fig. 10.2 $S'E$ is the R sine of the Sun's altitude. Multiplying this by R and dividing the product by the R sine of the colatitude is equivalent to dividing $S'E$ by $\cos \phi$ where ϕ is the latitude. This gives $S'U$ or $S'T$ of figure 10.4. Subtracting from this the earthsine UR, we get $S'L$. Multiplying this by R and dividing by the day-radius is equivalent to dividing it by $\cos \delta$. The result is equal to MH of Fig. 10.3. The arc corresponding to MH is ME. On adding to this the ascensional difference EC we obtain the arc MC which gives the time since sun-rise.

If we subtract $MG=MH+CF$ from the *antyā* QK, we get the distance QJ which is the versesine of the arc QM which gives the *natakāla*.

Bhāskara I gives two other methods both of which are essentially the same as the above method. Knowing the time from sun-rise, it is possible to determine the *lagna* (orient ecliptic point) after taking into account the precession of the equinoxes.

Assuming that the declination of the Sun does not change appreciably on any day, it is possible to determine the equinoctial shadow by measuring two shadows of the gnomon on any day. Writing b for *bhuja*, a for *karṇa-vṛttāgrā*, and s for the equinoctial shadow and taking into account their signs, the relation between them can be written as :

$$b = a - s.$$

If the two shadows have the same direction and all quantities: in the above equation are positive,

$$b_1 = \frac{H_1 \sin \delta}{\cos \phi} - s \text{ and } b_2 = \frac{H_2 \sin \delta}{\cos \phi} - s.$$

From these two equations, we obtain

$$s = \frac{b_1 H_2 - b_2 H_1}{H_1 - H_2}.$$

If the shadows are in opposite directions of the east-west line, then writing $-b_2$ for b_2, we obtain :

$$s = \frac{b_1 H_2 + b_2 H_1}{H_1 - H_2}.$$

From the equinoctial shadow we can obtain the corresponding hypotenuse. Now multiplying the shadow by R and dividing by the hypotenuse we can obtain the R sine of the latitude and the corresponding arc divided by 60 gives the latitude of the place in degrees.

The measurement of the midday shadow gives the Sun's zenith distance at midday. If this is Z, we have $\delta = Z = \phi$ or $\phi - Z$ according as $Z > \phi$ or $Z < \phi$ if the sun is to the south of the zenith. If the Sun is to the north of the zenith then $\delta = \phi + Z$. From a knowledge of δ, one can then calculate λ by the equation

$$\text{Sin } \delta = \text{Sin } \lambda \sin \epsilon.$$

This will give a value of $\lambda < 90°$. One can then obtain the correct value of λ from a consideration of the seasons. If the Sun is in the second quarter, this angle has to be subtracted from 180°; if the Sun is in the third quarter; it has to be added to 180°, and if the Sun is in the fourth quarter, it has to be subtracted from 360°. This will give the *sāyana* longitude of the Sun. From this the precession of the equinoxis has to be subtracted to get the true longitude of the Sun which would otherwise be obtained from *ahargaṇa.*

THE YASTI OR STAFF

The use of the Yaṣṭi for determining different astronomical quantities depends on the assumption that the declination of the Sun does not change substantially on any particular day. These determination therefore are more accurate when the time of observation is near the summer or the winter solstice.

For using the Yaṣṭi to make different measurements, one should draw on the ground, levelled with a water-level, a circle of radius equal to the length of the Yaṣṭi. One should draw the east-west and north-south lines by the method described earlier. At sun-rise one should determine the point where the Sun rises. This is done by placing one end of the Yaṣṭi at the centre of the circle and pointing the other end of the staff towards the Sun so that it gives no shadow. The distance of this point from the east-west line, multiplied by R, the radius of the great circle, and the product divided by the length of the staff, gives *agrajyā*, i.e. the distance OU in

fig. 10.2. This multiplied by the length of the gnomon and divided by the equinoctial hypotenuse gives OA, i.e. $R \sin \delta$. From this we get the radius of the diurnal circle. Multiplying this by the length of the staff and dividing by R we get the radius of the diurnal circle to be drawn on the ground with the same centre.

Now at any time of the day when we wish to determine the time from sun-rise, we place one end of the Yaṣṭi at the centre of the circle and point the other end towards the Sun so that it gives no shadow. We now measure the distance between the sun-rise point on the first circle and the top of Yaṣṭi. This distance then used as a chord on the diurnal circle drawn cuts off an arc, the number of degrees of which divided by six give, in the forenoon, the number of *ghaṭikās* from sun-rise, and in the afternoon the number of *ghaṭikās* to sunset.

If the length of the Yaṣṭi is equal to R, it is plain that the distance between the rising point and the top of the staff is the chord of the arc of the diurnal circle passing through the sun, intercepted between the horizon and the Sun. For this reason, the arc subtended by the distance in question in this interior circle, described with a radius equal to the diurnal circle, will denote the time after sun-rise or to sun-set.

Alternatively, one can take half of the chord, multiply it by the radius R, divide the product by the radius of the diurnal circle drawn and find the arc corresponding to this resulting half chord. Then twice this arc will be a measure of the time from sun-rise or to sun-set.

If the length of the Yaṣṭi itself is equal to R, the radius of the great circle, it is not necessary to multiply the measurements by R and divide the product by the length of the staff. We will assume herein after that the length of the staff is equal to t he radius R.

The perpendicular let fall from the point of Yaṣṭi on the ground is called the *śaṅku* or *mahāśaṅku* to distinguish it from the ordinary *śaṅku* or Gnomon of 12 aṅgulas. It is equal to the R sine of the altitude of the Sun. The distance between the *śaṅku* and he rising-setting line is called the *śaṅkutala*. This is the distance EU in fig. 10.2. where S' is the position of the Sun on the diurnal circle. Multiplying the *śaṅkutala* by 12 and dividing by the *śaṅku*, we obtain the equinoctial shadow. This is easily seen from the similarity of the triangles $S'EU$ and OGH, where OG is the gnomon of 12 aṅgulas and GH the equinoctial shadow.

The distance between the *śaṅku* and the east-west line is known as the *bhuja*. This is EO in fig. 10.2. If we observe two *śaṅkus* and find out the *bhujas* for them, then their difference when they are of the same denomination, and their sum when they are of the opposite denominations, when multiplied by 12 and the product divided by the difference of the two *śaṅkus* gives the equinoctial shadow. In fig. 10.2,

if q, S' and A are three positions of the Sun on the diurnal circle when the *śaṅkus* are observed, it is clear that :

$$GH = \frac{(DO—EO)\ OG}{q\ D—S'E} = \frac{(EO+OF)\ OG}{S'E—AF}.$$

If the *śaṅku* is observed at three different times by the Yaṣṭi, it is possible to determine with their help the equinoctial shadow, declination etc. of the three *śaṅkus*, one should be in the morning, the second near midday and the third near the evening. A thread is now drawn from the top of the first to the top of the third. Now a thread is drawn from the top of the second *śaṅku* to the eastern and western points of the horizontal circumference drawn on the ground so as to touch the thread drawn between the first and third *śaṅkus*. The line drawn, so as to connect the two points on the horizontal circumference, will be the rising-setting line and the distance between this line and the centre will give the *agrā* or R sine of amplitude. The line drawn through the centre parallel to the rising-setting line at the distance of the R sine of the amplitude is the east-west line.

Since the tops of the three *śaṅkus* are in the plane of the diurnal circle, the line drawn from the top of the first *śaṅku* to that of the last; will also be in the same plane. Hence the two lines drawn, touching this line, from the top of the second *śaṅku* to the circumference of the circle drawn on the ground will also be in the same plane. Thus the two points on the horizon, one to the east and the other to the west, and the line joining them are in the plane of the diurnal circle and the line is the rising-setting line.

One can now determine the equinoctial shadow as before and also the equinoctial hypotenuse, GH and OH respectively in fig. 10.2. From the similarity of the triangles OGH and OAU, one determines OA, R sine δ, by multiplying by 12 the R sine of the amplitude and dividing the product by the equinoctial hypotenuse. This again multiplied by the radius and the product divided by R sine of the Sun's greatest declination will give the R sine of the *bhuja* of the Sun's longitude. Thus we can get the *sāyana* longitude of the Sun.

Again taking two tubes equal in length to the radius of the circle drawn on a raised level surface and joining them at one end by means of a nail so as to form *V*-shaped tubes, one can simultaneously observe the Sun through one tube and the Moon through the other tube. Then putting their junction on the centre of the circle and their tips on the circumference graduated with the 360 divisions of degrees, one can determine the number of degrees between the Sun and the Moon. These when divided by 12, give the *tithis* elapsed in the light half of the month or the *tithis* to elapse in the dark half of the month.

By a similar method one can determine the angle between two planets. For this purpose, one observes one of the planes by pointing one of the tubes in the east-west

direction. One then rotates the other tube in the north-south direction at the proper angle so as to observe the other point. The arc between the two tubes gives the angle between the planets.

In order to determine the *agrā* of a planet, one should take a yaṣṭi in the form of a needle and put it on the circle, on the raised platform, along with the east-west direction. One should now put another needle at its western end at right angles to the first needle. The second needle should be chosen to be of such a length that the observer with his eye at the top of it and his line of sight passing through the other end of the first needle sees a planet rising at the horizon in the same straight line. Then one can find the *agrā* of the planet by multiplying the length of the second needle by R and dividing the product by the length of the first needle.

By taking a yaṣṭi and directing it towards the north on a level surface and putting the eye at the lower end of the yaṣṭi, it is adjusted in such a way that its tip is directed at the pole star. Then the perpendicular from its tip on the level surface is the *bhuja* and is proportional to the R sine of the terrestrial latitude and the distance between the base of the perpendicular and the base of the staff is proportional to the R-sine of the terrestrial colatitude and is called the *koṭi*. The *koṭi* multiplied by 12 and divided by the *bhuja* gives the equinoctial shadow.

The Cakra-Yantra

The Cakra-Yantra has been described by Varāhamihira as follows :—

"Take a circular hoop, on whose circumference the 360 degrees are evenly marked, whose diameter is one *hasta* and which is half an *aṅgula* broad. In the middle of the breadth of that hoop make a hole. Through this small hole made in the circumference allow a ray of the Sun at noon to enter in the oblique direction. The degrees, intervening on the lower half of the circle between (the spot illuminated by the ray and) the spot reaching by a string hanging perpendicularly from the centre of the circle, represent the degrees of the zenith distance of the midday Sun."

It is not explained how the time will be determined. Other astronomers recommend that the Cakra-Yantra should be made of in the form of a plate of metal or seasoned wood and a needle should be fixed at the centre, the shadow of which, when the instrument is held so that both sides of the circle are illuminated by the rays of the Sun, will give the angular height of the Sun from the number of degrees between the point where the shadow falls and the point representing the horizon which is at a distance of three signs or 90° from the point at which it is suspended. For accuracy the Cakra-Yantra should be made of metal and be about 3 metres in diameter.

Bhāskara II says that some former astronomers have given the following rule for making a rough calculation of the time, viz. multiply the half length of day by the obtained altitude and divide the product by the meridian altitude of the Sun and the

quotient will be the time sought. But Brahmagupta had already criticized this rough method of determining time. According to him, the *iṣṭahṛti* should be obtained by multiplying the sine of angular height by the radius of the diurnal circle and the equinoctial shadow and dividing the product by the gnomon length and the time determined as already explained in the section on determining time by the gnomon.

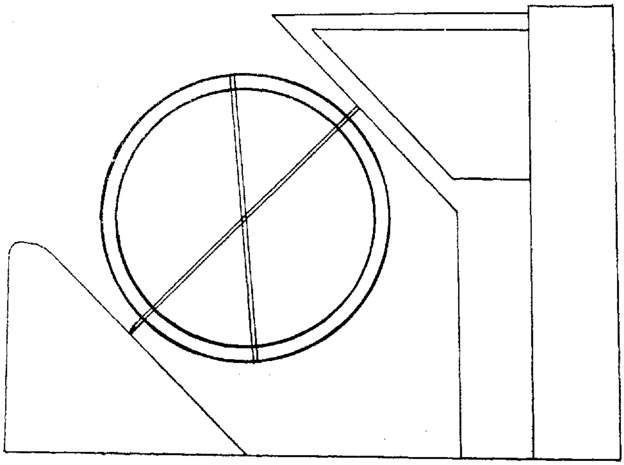


Fig. 10.8.

For his observatories at Jaipur and Varanasi, Maharaja Sawai Jai Singh built Cakra-Yantras which are very large instruments. There are two instruments at Jaipur each 6 feet in diameter and one at Varanasi, 3 feet 7 inches in diameter, one inch thick and two inches broad, faced with brass, on which degrees and minutes are marked. They are mounted on pillars and fixed so as to revolve round an axis parallel to the earth's axis. At the southern extremity of this axis, and on the pillar which supports the instruments (fig. 10.8), is a graduated circle in the plane of the equator. The axis carries a pointer, which indicates the hour angle on the fixed circle, and the main movable circle carries an index and a sighter through which heavenly bodies can be observed.

There are certain prominent stars which are very near the ecliptic. They are Puṣya (δ-Cancri; $\lambda=128°\ 1'$, $\beta=0°5)'$, Maghā (α Leonis, Regulus; $\lambda=149°8'$, $\beta=0°28'$), Śatabhiṣaj (λ-Aquarii; λ-$340°53'=\beta=0°23'$) and Revati (ξ-Piscium; $\lambda=19°11'$, $\beta=0°13'$). Here λ is the celestial longitude and β the celestial latitude. The circle should be so held that, when looking from its bottom and along its plane, the above stars may appear to touch its circumference. The plane of the circle will then be in the plane of the ecliptic. While observing any of the stars, one should observe a planet and determine the distance between the star and the planet. This distance when added to the longitude of the star when the star is to the west, and subtracted from the longitude of the star when it is to the east of the planet, will give the planet's longitude. We have given above the modern values of λ and β which do not change too much from year to year.

DHANURYANTRA

Half the circle is the *cāpa* or Dhanuryantra of which the circumference is divided into 180° and the sub-divisions of a degree. At its centre a fine hole is made through which a needle is inserted. It is held in such a way that the chord is horizontal, i.e. the central part of the circumference is resting on the ground. Then it is rotated so that both sides are equally illuminated by the rays of the Sun as in the case of the Cakra-Yantra. Then the number of degrees between the point where the shadow of the needle falls on the circumference and the nearer horizontal line give the altitude of the Sun and the number of degrees between the shadow point and the lowest point of the circumference give the zenith distance of the Sun. From this the time from sun-set can be calculated as described earlier.

The Dhanuryantra should also be large in size so that the observations may be accurate.

But the Dhanuryantra described by Āryabhaṭa seems to be a little different in the manner of its use. We give below the translation given by K. S. Shukla.

"The chord of the Dhanuryantra is equal to the diameter of the circle (i.e. the perfect circle), and its arrow is equal to the radius. It is mounted on the circle vertically with the two ends of its arc coinciding with the east and west points. The eastern end of the Dharnuryantra should be moved along (the circumference of) the circle until the Dhanuryantra is towards the Sun. The shadow of the gnomon will then fall along the chord of the Dhanuryantra, and (the shadow-end being at the centre of the circle) the distance between the gnomon as measured from the centre of the circle, will always be equal to the shadow for desired time. The degrees intervening between the (eastern) end of the Dhanuryantra and the rising point of the sun divided by six, give the *ghaṭis* elapsed in the day".

It seems the chord end of the Dhanuryantra described by Āryabhaṭa was placed on the ground and the gnomon could be moved on the circumference and placed in such a way that its shadow falls on the centre. If now a plumb line is suspended from the gnomon, its distance from the centre along the diameter will give the shadow for the desired time.

The Turīya-Yantra or the Quadrant

The Turīya-Yantra is so named because it forms the fourth part of a circle. For accuracy, it should be made of metal which is absolutely flat and each arm of which is about 1.5 metres in length. It should be graduated into 90° and each degree should also be sub-divided. It can be used to determine the obliquity of the ecliptic. For this a small nail, machined on a lathe, is fixed at the centre. The quadrant is now put in the meridian plane with the help of the north-south direction drawn on a circle on local ground by the method already described. One arm of the quadrant is horizontal and the other vertical, The end of the shadow of the nail on the graduations

of the quadrant then gives the zenith distance of the Sun at any time. The zenith distance at midday is least on the day when the Sun enters the sign of Cancer and the midday zenith distance greatest on the day when the Sun enters the sign of Capricorn. The position of shadow on these days is noted and half the angular distance between these two positions gives the obliquity of the ecliptic.

In another form a small tube is fixed at the centre pointing towards the point on the circumference along one of the arms. Another small tube is fixed at this end pointing towards the centre. This end is known as the horizontal point while the point on the circumference at the end of the other arm is known as the sky point. A plumb line is suspended from the centre. The quadrant is now held in such a way that rays from the Sun entering the tube at the centre fall on the tube at the horizontal point. The number of degrees between this point and the position of the plumb line gives the zenith distance of the Sun and the number of degrees between the plumb line and the other side give the angular height of the Sun. From this the time from sun-rise can be calculated as described earlier. The Moon, the planets and the stars can be observed by placing the eye at the horizontal point and observing the heavenly bodies by directing the instrument at them so that they will be observed by the light entering both the tubes.

The *Yantracintāmaṇi* recommends that each arm should be divided into 30 parts and half chords parallel to the other arm should be drawn from each point. Also an index rod should be fixed to the tube at the centre rather loosely so that it will revole freely along the circumference. Most of the astronomical results can easily be obtained with this instrument.

An instrument of solid silver, made according to the directions of the *Yantra-cintāmaṇi* was presented by Maharaja Ram Singh of Kota to the Government of India and has been described by Mr. Middleton in the *Journal of the Asiatic Society of Bengal* (1899). This is shown in fig. 10.9. In this an index rod revolves freely in the vertical upon an axis at the centre of the plate and there is a tube about one sixth of an inch in diameter which runs along the whole length of one side of the instrument from the centre to the circumference. From this end of the circumference, degrees from zero to 90 are marked on an outer circle. On a slightly inner circle, the instrument is graduated from the other end to the first end into fifteen divisions.

When the Sun or any heavenly object is viewed through the tube, the position of the index rod on the outer divisions gives the zenith distance of the heavenly body. The position of the index rod on the inner circle multiplied by the semi-duration of the day and divided by the meridian altitude of the Sun will give a rough estimate of the *nāḍīs* elapsed since sun-rise. As already noted, this method of estimating the time was criticized by both Brahmagupta and Bhāskara II.

Along the twelfth division on the side on which the viewing tube is placed, the numbers 1, 2, 3 etc. have been written. It is evident that the position of the index rod on this line can be read with the help of these numbers and will give the length of

the shadow of a gnomon of length equal to 12 units at any time. On the equinoctial day, this will give the length of the equinoctial shadow and the position of the index rod on the outer circle will give the latitude of the place of observation.

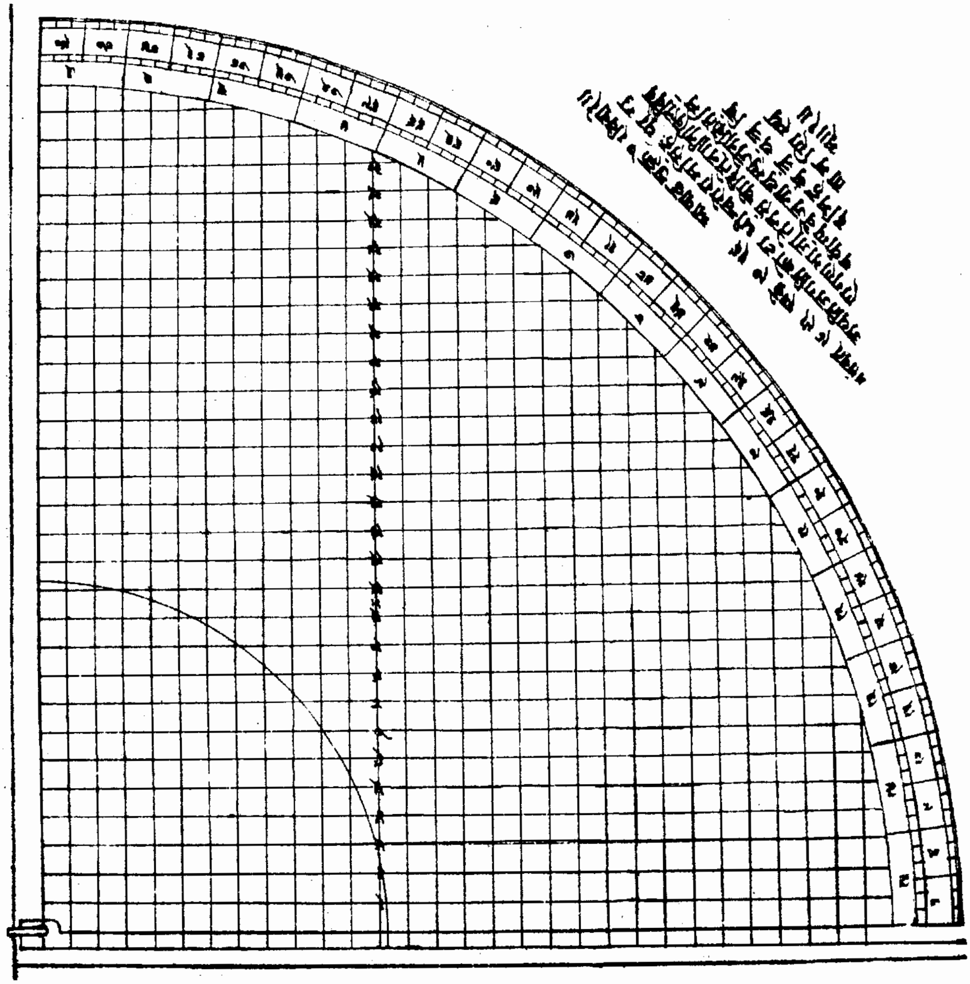


Fig. 10.9.

THE PHALAKA-YANTRA

The Phalaka-Yantra described by Bhāskara II, though similar to the Cakra-Yantra of Lalla and Śrīpati, is a great improvement on them as he uses in its construction the principles of spherical trigonometry so that it gives time, by the observation of the altitude of the Sun, much more accurately than that given by the instruments of the earlier astronomers, though, once its principles are understood, the determination of time is very easy. The directions given by Bhāskara II for its construction are as follows :—

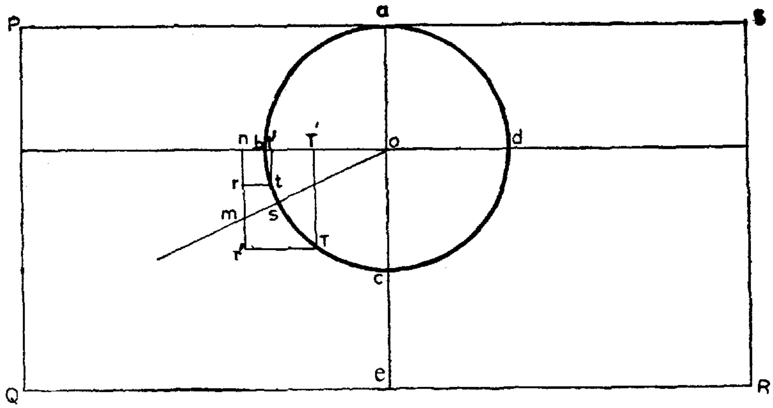


Fig. 10.10.

The astronomer should make a *phalaka* or board of metal or of good seasoned wood of rectangular form, 90 *aṅgulas* high and its double, i.e. 180 *aṅgulas* in length. At the middle point of the length he should attach a chain by which it can be held in the vertical plane. From this middle point a line is drawn which is perpendicular to the edge and is called the *lamba rekhā*. This perpendicular line should be divided into 90 equal parts, each of which will be equal to one *aṅgula*. Through each of the dividing points one should draw lines parallel to the top and bottom edges. These are called sines.

With the point of intersection of the 30th sine from the top and the *lamba rekhā* as the centre, he should draw a circle of radius equal to 30 *aṅgulas*. This circle will cut the *lamba rekhā* at the 60th sine and its diameter is equal to 60 *aṅgulas*. Now he should mark the circumference of the circle with 60 *ghaṭis* and 360 degrees and subdivide each degree into 10 *palas*. He should bore a hole at the centre of the circle and in it is to be placed a pin which is to be considered as the axis.

He should now take a thin *paṭṭikā* or index arm made of copper or of bamboo. This thin strip should be 60 *aṅgulas* in length, each *aṅgula* of which will be equal to the *aṅgula* of the *phalaka*. This should also be divided into 60 divisions. It should be half an *aṅgula* broad except at one end where it should be one *aṅgula* broad where a hole should be bored and the *paṭṭikā* is so suspended from the pin on the board that one side of the *paṭṭikā* may coincide with the *lamba rekhā*.

In fig. 10.10, *PQRS* is the board 180 units long and 90 units high. In it *aOce* is the *lamba rekhā* and $aO=30$ units. With *O* as centre and *Oa* as the radius the circle *abcd* is drawn. The index arm is of length *Oe* and is inserted at *O*. The hole in the index arm is so adjusted that when the index arm is suspended from *O* one side of the index arm coincides with *Oe*.

The rough ascensional differences in *palas* determined by the *khaṇḍakas* or parts divided by 19, will here become the sines of ascensional differences adapted to this instrument.

The R sin (ascensional difference) $= R \tan \phi \tan \delta$, and the rough values of the arcs corresponding to the first, second and third signs at a place, when the equinoctial shadow is one *aṅgula*, are 10, 8 and $3\frac{1}{3}$ *palas* respectively. These are the values when $R=3438$. When the radius is 30, the arcs corresponding to the three signs will be these values multiplied by 30 and divided by 3438. If we wish to find the arcs in *asus*, they will have to be further multiplied by 6. Hence the arcs in *asus* corresponding to the three signs will be $(10, 8, 3\frac{1}{3}) \times \frac{30 \times 6}{3438} = (10, 8, 3\frac{1}{3})/19$. These will be the values for the instrument devised by Bhāskara II. Since the arcs involved are small the *jyā* corresponding to these values will also approximately be the same.

The numbers 4, 11, 17, 18, 13, 5 multiplied severally by the equinoctial hypotenuse and divided by 12, will be the *khaṇḍakas* or portions at the given place; each of these being for each 15 degrees (of the *bhuja* of the Sun's longitude) respectively. The *sāyana* longitude of the Sun should be found by applying the correction due to the precession of the equinoxes and adding together as many *khaṇḍakas* or portions as correspond the *bhuja* of the Sun's longitude above found, and the sum should be divided by 60 and the quotient obtained should be added to the equinoctial hypotenuse. The result is now multiplied by 10 and divided by 4. The quotient here is called *yaṣṭi* in digits and the number of digits thus found is to be marked off on the arms of the *paṭṭikā* counting from its hole penetrated by the axis.

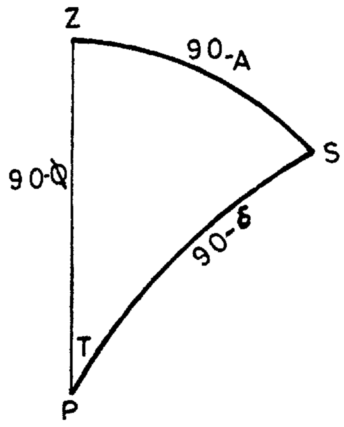


Fig. 10.11.

The theory involved in the above can be understood by reference to fig. 10.11. Let P, S and Z be the position of the north pole, the Sun and the zenith respectively. If A is the altitude of the sun, the arc ZS is $90°-A$. If δ is the north declination of the Sun, the arc PS is $90°-\delta$. If ϕ is the latitude of a place, the arc PZ is $90°-\phi$. Now, in the spherical triangle PZS,

$$\cos(90-A) = \cos(90-\delta)\cos(90-\phi) + \sin(90-\delta)\sin(90-\phi)\cos T,$$

or $\sin A = \sin\delta \sin\phi + \cos\delta\cos\phi\cos T,$

or $\cos T = \dfrac{\sin A - \sin\phi\sin\delta}{\cos\phi\cos\delta}$

where T is the time to midday or from midday. If the Sun is in the southern hemisphere, δ is negative. Hence we have

$$R\cos T = \frac{R\sin A}{\cos\phi\cos\delta} \mp R\tan\phi\tan\delta$$

$$= \frac{R\sin A}{\cos\phi\cos\delta} \mp R\sin\text{ (ascensional difference)},$$

according as the diclination is north or south.

Now, $\dfrac{1}{\cos\phi} = \dfrac{h}{12}$, where h is the equnoctial hypotenuse of gnomon of 12 *aṅgūlas*.

Therefore

$$R\cos T = \frac{h}{12}\,\frac{R\sin A}{\cos\delta} \mp \sin\text{ (ascensional difference)},$$

$$= y\sin A \mp R\sin\text{ (ascensional difference)},$$

where $y = \dfrac{h}{12}\,\dfrac{R}{\cos\delta}$ and is called that *Yaṣṭi*

$$\text{Now, } y = \frac{h}{12}\,\frac{R}{\cos\delta} = \frac{R}{12}\cdot\frac{h}{12}\left(\frac{12}{\cos\delta}\right) = \frac{R}{12}\cdot\frac{h}{12}\left[12 + \frac{12(1-\cos\delta)}{\cos\delta}\right],$$

$$= \frac{R}{12}\left[h + \frac{h}{12}\,\frac{12(1-\cos\delta)}{\cos\delta}\right].$$

When the *bhuja* of the Sun's longitude is 15, 30, 45, 60, 75, 90, the value of $12(1-\cos\delta)/\cos\delta$ is 4, 15, 32, 50, 63, 68 sixtieths respectively. The differences of these values are 4, 11, 17, 18, 13, 5 which have been given above. On multiplying the differences by h, the equinoctial hypotenuse, and dividing by 12, the quotients found are called the *khaṇḍas* for the given place. By assuming the *bhuja* of the Sun's longitude as an argument, one has to find the result through the *khaṇḍas*. Let r be this result. Then,

$$y = \frac{R}{12}\left(h + \frac{r}{60}\right),$$

$$= \frac{10}{4}\left(h + \frac{r}{60}\right),$$

because in the instrument $R = 30$.

Thus,

$$R \cos T = \frac{10}{4}\left(h + \frac{r}{60}\right)\sin A \mp R \sin \text{ (ascensional difference)}.$$

It is evident that the value of the *yaṣṭi*, y will always be greater than 30 because h is always greater than 12 except at the equator where h is equal to 12. At the equator the *Yaṣṭi* will be equal to 30 only if $\delta=0$. If on holding the instrument so that the rays of the Sun shall illuminate both its sides (to secure its being in a vertical plane), the shadow of the axis at O cuts the circumference of the circle $a\ b\ c\ d$ in s, the angle sob is equal to the angular height of the Sun.

Now the index arm is put on the axis and putting it over the place where the shadow cuts the circle and measuring along the index arm a length equal to the *yaṣṭi* found above, let m be the point so obtained. Then,

$$mn = y \sin A,$$

if the place is at the equator, we have to find T such that $R \cos T = mn$. Then T gives the value of time in degrees to or after midday.

At any other place, the correction on account of the ascensional difference has to be applied. If the Sun is in the northern hemisphere R sin (ascensional difference) has to be substracted from mn. Let the amount to be subtracted be mr. Then R Cos $T = tt'$ and the angle is given by the arc Ct. If the Sun is in the southern hemisphere, the amount mr', the correction due to the ascensional difference, has to be added and $R \cos T = TT'$ and the angle is given by the arc CT.

Once a table of the values of the *yaṣṭi* and of the correction on account of the ascensional difference for the different *bhujas* of the Sun's longitude for a particular place has been constructed, the instrument will give the time very easily and quickly.

The Kapala-Yantra

The Kapāla-Yantra described by Varāhamihira and others is very different from the Kapāla-Yantra described by Āryabhaṭa and *Sūrya-siddhānta*, the latter being actually water instruments. This instrument is a hemisphere with a gnomon in the centre. The length of the gnomon is equal to the radius of the hemisphere so that the upper tip of the gnomon is at the centre of the hemisphere. It is placed on even ground and raised so that the elevation is equal to the latitude of the place and plane of its rim coincides with the plane determined by the east-west line and the direction of the north pole. Thus the gnomon points towards the point of intersection of the meridian circle and the celestial equator. The instrument may be made of metal or of good wood. At the centre of the hemisphere also cross two wires stretched between the east-west and north-south points of the rim.

On the rim the signs of the zodiac are marked in the reverse order. At the time of sun-rise the instrument is rotated so that the shadow of the gnomon falls on the sign in which the Sun is. As the sun rises the shadow of the gnomon point moves downwards from which the angular height of the Sun may be obtained. And thus the time since sun-rise can be calculated as well as the sign which is at the horizon at that instant may be obtained. This has already been discussed earlier.

THE NALAKA-YANTRA

This is a simple little tube formed generally of bamboo. Its use is only to verify the correctness of the computation of the shadow and *bhuja*. If the computation is wrong the planet will not be seen in the direction indicated by the values of the computed *bhuja* and *koṭi*. If the planet is in the east, the computed *koṭi* must be marked in the west, but if the planet is in the western hemisphere, it must be marked in the east. The *bhuja* is now marked in its own direction and the shadow is the hypotenuse of the right-angled triangle formed by the *koṭi* and the *bhuja*. A thread connecting the point of the intersection of the *bhuja* and the shadow to the top of the gnomon forms the *chāyākarṇa*. If now the tube is directed along the direction of the *chāyākarṇa*, the planet will be visible.

In actual practice the Nalaka-Yantra is mounted on two bamboo sticks, so that its lower end is at the height of the eye and it is pointing the direction of the *chāyākarṇa*. In the case of the Sun, one can actually observe the gnomon shadow or one can compute it knowing the declination etc. In the case of a planet, the shadow cannot be seen. But its *koṭi* and *bhuja* can be calculated from its computed position and its declination. The Nalaka-Yantra will then verify the correctness of the computation.

One can see the reflection of the planet in water. Since the angle of incidence is equal to the angle of reflection, the reflected light will be making the same angle with the surface of water but will be directed upwards in the plane of the incident ray. The Nalaka-Yantra will have thus to be directed downwards by the same amount as it was previously raised upwards while making the direct observations.

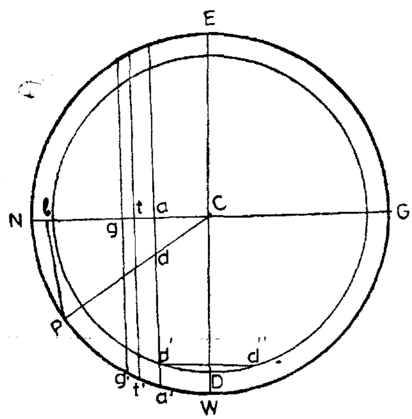


Fig. 10.12.

The Indian astronomers had developed certain graphical methods to determine astronomical quantities. One of these, described by Varāhamihira, is a method to determine the ascensional difference of the different signs. Here a circle of diameter one hundred and eighty *aṅgulas* is drawn on level ground. The prime vertical, the zodiacal signs and 360° and the declinations of the signs are marked. This is done in fig. 10.12. *ENWS* is the circle with diameter equal to 180 *aṅgulas*. On this the declinations of the first three signs are indicated as *Wa*, *Wt'* and *Wg'*.

Lines parallel to EW are drawn through a', t' and g' meeting the line NS in a, t and g respectively. Then aa', tt' and gg', are respectively the radius of the day circles when the Sun is at the end of the first three signs. With the same centre C, one has to draw these other circles with radii equal to aa', tt' and gg' (only one of these with a radius equal to aa' is drawn in the figure). One now cuts off the arc NP equal to the latitude of the place and joins the line CP which cuts aa' in d.

Now we measure a chord $d'd''$ equal to twice ad. Then arc $d'd''$ is equal to twice the ascensional difference for the first sign. Since

$$\frac{ad}{ac} = \frac{Pl}{lc} = \frac{R \sin \phi}{R \cos \phi}$$

$$ad = ac \tan \phi,$$

$$= R \sin \delta \tan \phi.$$

This is what is known as the earth sine. If the angle subtended by the arc $d'd''$ at the centre is 2θ,

$$R \cos \delta \sin \theta = \frac{d'd''}{2} = R \sin \delta \tan \phi,$$

$$\text{or} \quad R \sin \theta = R \tan \delta \tan \phi$$

which is the *cara-dala-jyā*. The corresponding angle is the right ascension. Similarly we can get the *vināḍikās* corresponding to Aries+Taurus and Aries+Taurus+Gemini from the interesection CP with tt' and gg' respectively and the two circles with radii tt' and gg' which have not been drawn in fig. 10.12.

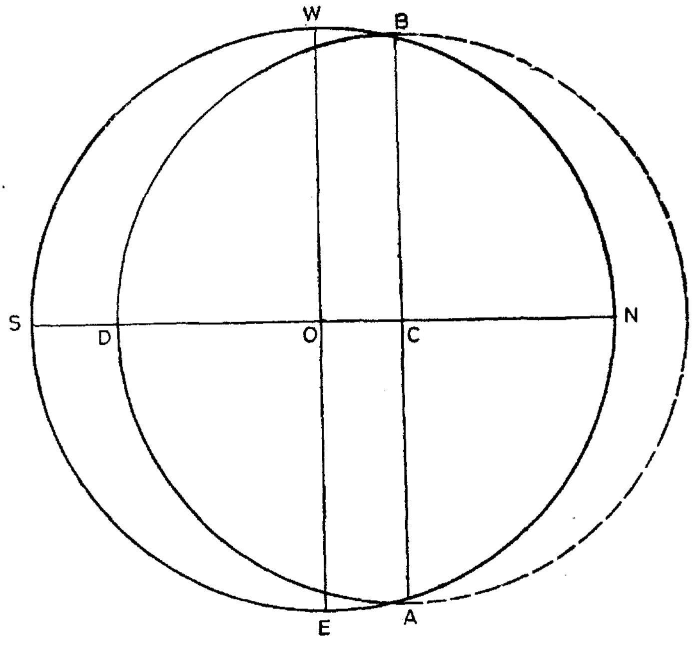


Fig. 10.13.

Āryabhaṭa has described a Chāyā-Yantra shown in fig. 10.13. On level ground a circle $NWSE$ is drawn with Centre O and radius equal to 57 *aṅgulas* which is equal to the number of degrees in a radian. The north-south and east-west directions are drawn on it as explained before. The R sines of the Sun's declination and the Sun's longitude are now determined from the hypotenuse of the shadow of the gnomon when the Sun is on the prime vertical or from the hypotenuse of the shadow when the Sun is in a mid-direction.

When the Sun is on the prime vertical, the shadow of the gnomon falls on the east-west line. The value of the *mahāśaṅku* when the Sun is on the prime vertical, i.e. the value of OB in fig. 10.2., is given by the relation :

$$OB = \frac{12\,R}{\text{hypotenuse when the Sun is on the prime vertical}}$$
$$= \frac{12R}{K},$$

where K = hypotenuse when the Sun is on the prime vertical.
Also from fig. 10.2, the R sine of the declination of the Sun is given by OA and $OA = OB \times \sin\phi$ where ϕ is the latitude of the place,

$$\text{or } OA = OB \sin\phi$$

$$\textit{The agrā } OU = \frac{OA}{\cos\phi},$$
$$= OB \tan\phi,$$
$$= \frac{12\,R \tan\phi.}{K}$$

knowing $R \sin\delta$, we can get the R sine $\lambda = \dfrac{R \sin\delta,}{\sin\epsilon}$ where ϵ is the obliquity of the ecliptic and λ is the longitude of the Sun.

But when the Sun is in the southern hemisphere, it never crosses the prime vertical. Then the midday hypotenuse is given by

$$H = \frac{12}{\cos(\phi + \delta)}$$

where H is the midday hypotenuse and δ is the southern declination of the Sun. From this δ, *agrā* and R sine of the longitude of the Sun can be determined.

The points A and B at the ends of the Sun's *agrā* are now laid off in the east and west in their proper direction and also OC is equal to the Sun's *agrā*. A is the point where the Sun rises in the east and B is the point where the Sun sets in the West and AB is the rising-setting line. With C as centre and CB as radius a circle BDA is drawn which is the diurnal circle for the day.

The gnomon is now so placed at the end of each *ghaṭī* that the end of the shadow may lie at the centre *O* of the circle. The point of the circle *BDA* where the shadow cuts it corresponds to that particular *ghaṭī*. *BDA* is thus marked in *ghaṭīs* and the intervals between the *ghaṭis* are equally divided into six degrees. The Chāyā-yantra constructed in this way is used to determine the *ghaṭis* and degrees elapsed since sun-rise.

The same circle cannot be used to determine the time for different days and 365 different circles will have to be drawn for the 365 days of the year.

None of the instruments described by Indian astronomers before the time of Maharaja Jai Singh survive today. Perhaps they were made of perishable materials like wood and bamboo. Admittedly also they were not very sophisticated. But it must be remembered that mechanical clocks had not been divised upto that time and it was not possible to measure time very accurately.

11 ASTRONOMICAL OBSERVATORIES

S. D. SHARMA

DEVELOPMENT OF ASTRONOMICAL OBSERVATORIES

In astronomical lore of ancients there were very few simple instruments. Naked eye observations were the earliest attempt to record astronomical events. The man observing his own shadow developed some empirical relations for knowing time lapsed after sunrise and also the time remaining of the day[1]. This way the use of gnomon (a vertical stick) started in a systematic fashion and the science of sciatherics (gnomonics) developed. At the same time or even earlier, water clock (clepsydra) might have been used in determining time. The rising and setting of Sun, Moon and stars, the waxing and waning of Moon's phases, lunar and solar eclipses and also the occultations of Moon and planets (like conjunction of Jupiter with δ-Cancri etc.) and other phenomena like heliocentric rising and setting of planets, etc. always fascinated the ancient man to have open air observatories.

We find a simple stick (or a *nalikā*, tube) and a thread being used for determining the diurnal rising and setting of Sun, Moon and planets, in the horizon of the locality[2]. This was the simplest instrument prepared by drawing a circle on ground and a stick was being used for pointing towards the disc of Sun, Moon or planet at the time of rising or setting. The thread (*davarikā* as sometimes it is called) was being used to draw geometrically the chords in the experiments as shown in fig. 11.1.

This is probably the first instrument in open-air observatory used for planetary observations. A simple stick and a tube too served the purpose to observe planets' conjunction etc. Along with it a gnomon [3] was being used for determining time. The gnomon might have been used for standardizing the amount of water in clepsydra on equinoctiol days.[4] These two instruments might have been used simultaneously for defining *muhūrtas*[5] during day and also during night from observations of Moon's shadow.[6] The observatories evolved from these open air collections having these simple instruments. We do not have any record of old observatories but there are scattered references like those of Emperor Babur mentioning the old observatory of Vikramāditya's time.[7] There is no doubt that the instruments were evolving gradually as evidenced from studies of astronomical texts in chronological fashion. When the spherical nature of shape of the Earth was established, a geometrical globe was developed as described in last chapter of *Sūrya-siddhānta*.[8] This instrument gave birth to a celestial globe when the astronomical circles like celestial equator, ecliptic etc. were defined. The *khagola*[9] (celestial sphere) was prepared by using wires or wooden splinters. The present recension of *Sūrya-siddhānta* mentions the setting of this instru-

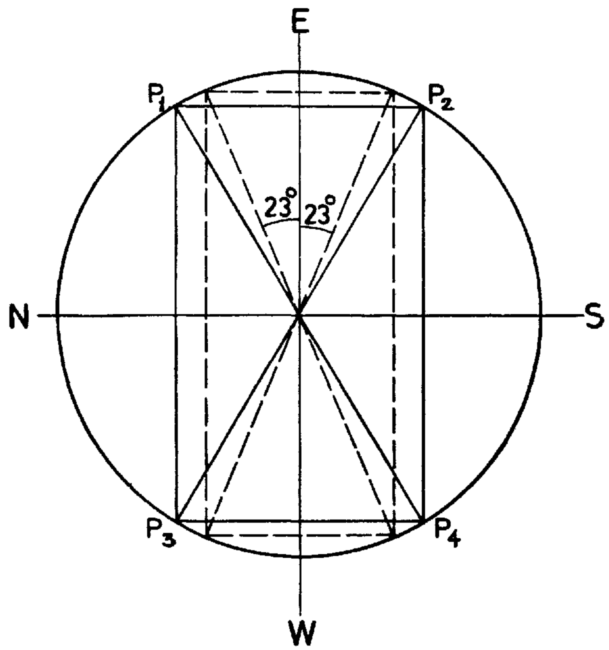


Fig. 11.1.

1. Cardinal coordinates used for celestial bodies at the time of rising due to diurnal motion in ancient astronomical tradition as in Vedaṅgajyotiṣa, Śulbasutras Sūryaprajñapti etc.

2. The height of planets etc. was defined w.r. to cardinal point S and was measured simply by geometrical construction. It was declinational height profected on the earth.

ment which in a bigger shape formed the armillary sphere used in observatories. It also gives some details of instruments like.

(1) Yaṣṭi the instrument already described, fig. 7.6..

(2) Dhanu (arc with chord) to be used for observing rising or setting celestial bodies, with the help of *śara* (the arrow) formed of a stick.

(3) Cakra, the wheel like instrument used for determining declination etc. or even for determining time by observing transits of stars.

(4) Watches being run with the help of sand, water, oil etc. Water clocks made in the shape of *mayūra* (peacock) and monkey-shaped Yantras.

(5) Kapāla-yantra (Bowl shaped water clock) with a thread in its hole.

(6) Gnomon or Nara-yantra,[9] [10] of 12 *aṅgulas*.

All these instruments constituted observatories in older times. Later in treatises like Brahmagupta's, Lalla's etc. and in *Siddhānta-śiromaṇi* of Bhāskarācārya, we find more detailed descriptions of astronomical instruments.[11] Bhāskarācārya discusses the following instruments :

(1) *Golayantra, the armillary sphere*—A sphere in which all movable and fixed circles are designed and the observer can perform observations sitting within the sphere itself. Āryabhaṭa-I has given little details of this instrument,[12] but Brahmagupta and Lalla have given similar elaborate details. This instrument although inconvenient to use, serves the purpose of an astrolabe. It may be remarked that Bhāskarācārya performed lunar observations with the help of this instrument and compiled his *Bījopanaya*[13] in which he discusses the variable corrections (sinusoidally varying corrections) to the moon.

(2) *Cakra-yantra*—A wooden or metallic wheel like structure with an axis fixed in a hole at its centre. It was fixed in the plane of ecliptic with the help of *yogatārās* of Puṣya, Maghā, Śatabhiṣaj and Revatī, which have almost zero latitude. It was used to determine longitudes and latitudes of planets.

(3) *Cāpa-yantra*—Just half the structure of Cakra-yantra.

(4) *Turīya-yantra*—Only one quadrant of the Cakra-yantra with a stick or *nalikā* (tube) for observing celestial bodies in order to determine their zenith distances and altitudes.

(5) *Nāḍīvalaya*—A Cakra in the plane of the equator used to determine directly timings of rising and setting of signs, horā, dreṣkāṇa, navāṃśa, etc.

(6) *Ghaṭī-yantra*—A *droṇa* (bowl-shaped) water-clock with a hole of standardized size at its bottom.[14]

(7) *Nara* or *Śaṅku* (the gnomon) made of ivory or a metal.

(8) *Phalaka-yantra*—A plank with a circle of radius 30 *aṅgulas* drawn on it. The circle is graduated in *ghaṭīs* and degrees. A *paṭṭī* of half *aṅgula* width and of length 60 *aṅgulas* (and some additional length of one *aṅgula* for fixing) is fixed in the axis through the centre of the circle. The axis forms a gnomon. The instrument is made to hang with the help of a chain. The *paṭṭī* is placed passing through the shadow on the circumference of the circle. When hanging in the plane of vertical circle, the instrument can read zenith distance directly through graduations on the circle. An additional attachment *yaṣṭi* is prepared by analytically computing its length using the latitude of the place of observation and the subsequent ascensional difference at the time of observation. This helps determining the hour angle of the Sun (and hence the time) just geometrically without going into the detailed computations.

(9) *Yaṣṭi-yantra*—consists of a circle with radius=the radius adopted for the chord sines in the text and east-west north-south points are marked on it. There is another concentric circle with radius=*dyujyā*=sin (codeclination)=R Sin (codeclination). The line joining the rising and setting points on the horizon is the *udyāsta-sūtra*. A *yaṣṭi* (rod) of length=radius R is used to point towards the Sun so that its shadow vanishes. This way the Sun is at the tip of the *yaṣṭi* (the *yaṣṭi* is to be rotated as the Sun moves along the *ahorātra-vṛtta* (diurnal circle) and consequently its hour angle changes). The distance between the tip of the *yaṣṭi* and the Sun's rising point is measured and a full chord (*jyā*) of this much length is drawn in the diurnal circle. The *ghaṭis* lying in the arc of this chord in the diurnal circle is the *unnatakāla* (i.e. lapsed time of the day after sunrise at the instant of observation). Bhaskarācārya has given various uses of this instrument.

(10) *Dhiyantra*—is the simple stick instrument (augmented by a plumbline like device to assign vertical direction). It was used to determine the heights and distances of objects by measuring the inclinations or angles of elevation (actually *bhuja* (x-coordinate) and *koṭi* (y-coordinate in Bhaskarācārya's treatment) at different points. The method is similar to the one depending upon parallaxes of terrestrial and celestial objects. This was used for determining heights, distances etc. by observing the objects also in water.[15] It may be remarked that in Bhāskarācāray's treatment geometry of refraction at an angle within water was not at all used. He used the facts like that the image of a vertically standing tree etc. within water is of the same size as the tree itself. In the solutions of problems by Bhaskarācārya the refraction does not occur, so his solutions are not affected by refraction. It may be remarked that laws of reflection were known to Indian astronomers of olden times,[16] but the laws of refraction were not discussed.

It may be remarked that in general these are the instruments described in standard treatises, but there are some variations or some additions by later astronomers. Gaṇeśa Daivajña (the author of *Grahalāghava*, śaka 1444) devised a whip like horizontal gnomon called the Pratodayantra (*Cābuka* instrument or the hunter sun-dial). A small booklet was written by him which was included by Munīśvara in his *Siddhānta-sārvabhauma*.[17] This is of cylindrical shape in which a gnomon of 1/6th of its size in holes (12 in number, one for each month) in the beginning of vertical columns. Thus there are 12 vertical columns graduated for observing shadows in all the 12 months throughout the year. There are other columns also to determine other parameters like *unnatāṃśas* (altitude) etc. too. The *Pratoda-yantra* was brought to light by Junnerkar of Pāṭana (Gujarat) in V. 1959,[18] and these are now found with some families too. This instrument was used to determine time during the day.

It is worthwhile to remark here that gnomonics in Indian tradition developed from ancient times to the time of Sawai Jai Singh. We find in Phalaka-yantra of Bhaskarācārya and in Pratoda-yantra of Gaṇeśa Daivajña the use of horizontal gnomons, while only vertical gnomons were being used in earlier works. In Sawai Jai Singh's instruments, we find the use of triangular gnomons and much more sophis-

ticated uses of the vertical and horizontal gnomons as well, which will be discussed in details in the next sections.

It may be remarked that gnomons were also used to determine obliquity, latitude, hour angle (in terms of lapsed time of the day) etc. too. In the *Sūrya-siddhānta*[19] there is described a method for observing planets at the time of conjunction through a mirror with the help of two gnomons.[20] Also the gnomons were used to determine time during night too using shadow of the Moon, but this was an inadequate and erroneous method to define *muhūrtas* in terms of hour-angles of the Moon, (as 5° latitude of the lunar orbit will introduce much error in these findings) We also find nocturnal instruments[21] in Indian tradition, which were used to determine time during night using observations of *dhruvamatsya* (fish-shaped group of polar stars including Polaris) and during day using observations of the Sun. This could be used to determine *lagna* (ascendant) also. A book entitled *Dhruvabhramana-yantra* was written by Padmanābha S/o Nārmada (śaka 1320=A.D. 1398). In fact this forms the second chapter of this book *Yantra-ratnāvali*, or *Yantrakiranavali*. We also have a text on practical astronomy by Cintāmaṇi Dixit named '*Golānanda* which discusses an instrument designed to give equations of centre of planets, radii vectors *(śighrakarṇas)*, true velocities *(spaṣṭagati)*, declinations, latitudes, ascensional differences, ascendant (*lagna*), direction, altitude, parallaxes in longitude and latitude etc. A commentary on this text was written by Yajñeśvara. Another book on practical astronomy was written by Srī Viśrāma in 1537 śāka. We also find a small text on Koṇeri-yantra which is an instrument similar to the Dhī-yāntra of Bhāskarācārya. There might have been developed many other instruments and texts on practical Hindu Astronomy of which we have no records available now. All these instruments were designed either to find correct time or to determine planetary positions.

OBSERVATORIES OF SAWAI JAI SINGH

From previous section it is clear that astronomical instruments had been developing since early *Vedāṅga Jyotiṣa* period upto the medieval times in the hands of exponents of siddhāntic astronomy. There were open air observatories for daily observations of rising and setting of Sun (also of Moon and planets) for determination of solar year etc. as described in *Śulba-sūtras* and *Sūrya-prajñapti*. At the time of these observations time measuring devices, gnomon and clepsydra, too might have been placed nearby the place of the observation. The gnomon might have been used to standardize or calibrate clepsydras. The units of time, *muhūrtas* and *ghaṭīs* and the shadow length and equivalent waters were standardized by simultaneous use of these two instruments. These two portable instruments and the simple fixed circular device augmented with *dawarikā* (thread), as already shown in fig. 7.6, formed the earliest open air observatory. Later on more instruments were added as they developed. Gnomonic experiments were performed throughout the year to determine seasons etc. in terms of locus of shadow. Circular structures on levelled grounds for use of gnomons in order to determine position declination of Sun formed better structure instruments. On measurements using such devices cardinal points were used as

coordinates and declinations as heights in diurnal paths. we do not have any records of those observatories now. But there are scattered references, for example, Emperor Bābur mentions of an observatory of Vikramāditya's time. He writes in his memoire.

"Another observatory was made in Hindustan, in the time of Hindu Raja Vikramāditya, in Ujjain and Dhāra that is the Malwa country now known as Mandu. The Hindus of Hindustan use the tables of this observatory. They were put together 1584 years ago".[22]

These days we have only the observatories of Jai Singh preserved. Rajā Jai Singh Sawāi A.D. (1686—1743) constructed observatories at Delhi, Ujjain, Jaipur and Varanasi. There was an observatory in Mathura which is now no more. About the origin of these we have the evidence in document *Ẓij Muḥammad Shāhi*. Lt. R. I. Gerrett worked on restoration of Jaipur observatory with the help of Chimman Lal Daroga, Pt. Chandradhara Guleri, Mistri Maliram and Shri Gokula Chandra Bhāvana.[23] Lt. Gerrett did not express his opinion about *Ẓij Muḥammad Shāhi*.

In 1918 after discovery of Ulugh Beg's observatory,[24] Department of Archaeology of Government of India examined the tables and concluded that Jai Singh's star-tables were ordered the same way as Ulugh Beg's. Longitudes differed by 4°.8 due to precession but latitudes were the same. Also the astronomical tables were similar to those of De La Hire's.[25] But according to the preface, Jai Singh himself constructed these tables. There are many discrepancies and anomalies in this text and thus these deserve special study for any conclusive inference. According to Kaye, Padre Manuel and Mohammad Sharif were sent to Europe and other countries and in A.D. 1728. Father Figuereda, a Portuguese Jesuit, was sent to Portugal. In spite of all the informations, Jai Singh did not use the then available astronomical equipments in his observatories. Jai Singh renovated these and developed some instruments of his own. Māna Mandira observatory was two hundred years earlier than Jai Singh, as is evidenced from A. Campbell and T. D. Pearge's records who visited this observatory in 1770 and stated that the observatory was built two centuries earlier.[26] It makes no sense to construct a new observatory on the roof of an old building. It is logical to accept that an old one might have been restored by Jai Singh. William Hunter[27] and later Kaye summarised that Banaras observatory was one of the five Jantar Mantars erected by Jai Singh, the four others being built in Delhi, Ajmer, Ujjain and Mathura. Tavernier and Prinsep visited India in 17th century A.D. at the time of reign of another Rajā Jai Singh and took it for Jai Singh's work. The records of instruments in Bhāskarācārya's and others' works and the reports on Vikramāditya's observatory show that the traditions of astronomical techniques were in vogue in India throughout all centuries from Pre-christian era to the time of Jai Singh in different parts of the country in spite of many invasions and political upheavals.

Now let us turn our attention towards the equipments in these observatories. On seeing the big massive masonary instruments in Jantar Mantars, the first question,

which occurs in one's mind is why Jai Singh constructed big stony structures leaving aside the metallic instruments which could easily be prepared during those daysö Here we try to view the problem faced by Jai Singh in the light of the back-ground of his astronomical achievements at that time.

The Reason why Jai Singh Resorted to Massive Masonary Instruments

Rajā Jai Singh was trained in his early years, in the field of Hindu astronomy but he was not satisfied with the use of old data on astronomical constants and wanted patterns advanced in comparison with those of earlier Indian astronomers. He interacted with scholars of Moslem world and got attracted to astrolabes and other metallic instruments. He got metallic instruments prepared with improvements and modifications which could give results in Indian astronomical tradition. According to *Zij Muāammad Shhāi.* (A.D. 1719—1748), he constructed Zat-al-Halqua (a spherical shape instrument *Golayantra*) with diameter = 3 gaz, Zat-al-Shabātain (an astrolabe with two parts *akṣs-patras* (discs for different latitudes) and *bhapatra* (disc with zodiac signs), Zat-al-Zaquātin and Sadas Fukhri (Shud-Sufkari in Arabic), (*Sqsṭthrωsa yantra* according to Jagannatha) and *Shnmlrh* (the word used by W. Hunter for Jai Prakash Yantra) etc. A number of such instruments are still preserved in repositories in Jaipur and Varanasi,[28]

After using these instruments he realized that these instruments although being very handy suffered from serious limitations on account of their small size, wear and tear, loosening of axes, back-lash errors, displacements of centres, shifting of planes of instruments, inequality of divisions and effects of weathers etc, and took this to be the reason for inaccuracies in works of Hipparchus, Ptolemy, etc. In order to get more accurate results he thought of constructing big masonary instruments which could be best set once for all and being stable were not liable to change their azimuth. His approach was similar to the one adopted by Mirza Ulugh Beg (A.D. 1394-1449) in Samarqand observatory in Central Asia. Greaves states that it had a quadrant used by Ulugh Beg as high as summit of St. Sophia in Constantinople or about 180 ft. Earlier Moslems too devised big instruments. Abul-I-Wafa (A.D. 995) used a quaquadrant of radius 21 feet and 8 inches. Al-Khojendi used a sextant with radius = 57 feet 9 inches.[29]

He[30] (Jai Singh) constructed in Dar-al-Khilafat in Shāh-Jahānbād (i.e. in Delhi) an observatory in which he erected instruments of his own invention, such as Jai Prakāśa Yantra, Rāma Yantra, and Samrāṭ Yantra, which had semidiameters of eighteen cubits and one minute on it is a barley corn and a half, of lime and stone of perfect stability and in eracting these much care was taken for rules of geometry in adjustments to meridians and to latitudes of the place. This way all types of errors could be rectified. The Delhi observatory got completed by A.D. 1724. In order to confirm the reliability of the results obtained through observations, he constructed similar observatories in Jaipur, Ujjain, Benaras and Mathura. The observations at all these observatories were found to tally well. Later he sent Pedra Manuel to Portugal and some others to European countries who brought astronomical charts,

tables and books. Jai Singh had also tables of Ulughbeg, Flamsteed, Tycho Brahe and Havelius, Said Gurgāni and Khāquāmi. On examining these tables and checking the computed results on the basis of European tables he found that the error in longitude of Moon was sometimes (near half-moon) as large as half a degree and at syzygies too there was some error resulting into error in predictions of eclipses. The times of solar and lunar eclipses were found to be in error to occur earlier or later by by 14th of a *ghaṭī* (=6 minutes). So Jai Singh's belief was confirmed that European instruments which were not of so big sizes suffered from errors. It may be pointed out that Flamsteed (1646-1719) used a sextant of just 6 feet radius, a 3 feet quadrant, a mural arc, (Yām Yottars, Bhitti yantra) of radius 7 feet. Jai Singh's big instruments at least had better provisions of readings with better accuracies, but later developments of theories based on law of gravitation and advancements in theories of error like level correction, azimuthal correction etc. to be applied theoretically as remedies for errors in setting of transit instruments etc. using vernier calipers and pitch devices surpassed the old techniques. It may be remarked that the errors in the longitude of Moon etc. were not only due to experimental inaccuracies in determinations of equations of centres etc. but in fact were mainly due to the lack of development of lunar theories etc. in the light of law of gravitation at that time. These theories went on improving upto the middle of 19th century or so. There is no doubt that the European developments in these theories upto the 1st quarter of 18th century could not convince Rajā Jai Singh to be any of the better techniques and this was the real reason why he resorted to masonary structures in constructing his original devices. (See next chapter on Jai Singh's knowledge of telescopic observations and their limitations).

Instruments in the Observatories of Jai Singh

Now we would like to discuss in brief the instruments set by Jai Singh in his observatories. It may be pointed out that the instruments in all these observatories were the same but with some variations in dimensions etc. Here first we discuss some of the instruments which are described by Bāpu-deva Śāstrī in his exposition on Māna-mandira observatory in Kāśī (Varanasi) in the year 1788 vaka (A.D. 1866).

These days Kāśī Observatory (25° 18′ N, 83° 1′ E) is in a very bad condition. Earlier, it had very good instruments upto 18th century A.D. as reported by Robert Barker (Commander-in-Chief in Bengal in 2nd half of 18th century A.D.)[31], whose report is the earliest on this observatory after Jai Singh. This was prepared for Royal Society of London. Further information was supplied by J. C. Williams in 1792 A.D. He gives the information that the Māna-mandira was much older. It was built for repose of pilgrims and holymen. On the top of this, the observatory was built by Jai Singh. The construction was begun in the year 1794 Vikram (A.D. 1737) and it took two years for completion. Rajā died in 1800 Vikram (A.D. 1743). In 1799 Hunter gave a brief description and spoke of the accuracy of William's descriptions. Sir Joseph Hooker made excellent drawings of the three instruments invented by Jai Singh. He recorded in his diary that the Kāśī Observatory was even then the most interesting monument although it was fast getting in

ruins. Paṇḍit Bāpudeva śāstrī,[32] Lālā Chiman Lal, Gokul Chandra Bhāvana,[33] G. R. Kaye[34] and others too have written about the instruments of this observatory.

Here we first describe the instruments of Kāśī observatory as described by Bāpudeva śāstrī in 1866 A.D.[35]

(1) *Yāmyottara-yantra (Mural quadrant)*

There is a Yāmyottara-yantra in the north-south direction in the form of a wall made up of lime brick-stones (hence the name *bhittiyantra*). It is $7\frac{1}{2}$ hands (1 hand = 24 *aṅgulas* = 3/2 feet) in height, 6 hands, and $1\frac{1}{2}$ *aṅgulas* in breadth and $16\frac{1}{2}$ *aṅgulas* in thickness. One of its sides, facing east is whitewashed and smoothened. On this side at the points near top corners there are fixed two gnomons *(śankus)* made of iron, which are separated by 5 [6] hands from each other and are fixed at a height of 7 hands less 2 *aṅgulas* from the ground. With the gnomons as centres and radii equal to the distance between them, there are drawn two intersecting quadrants. Below these both quadrants there are concentric quadrants which are uniformly divided consecutively in 15 parts (6° each), 90 parts (1° each) and 900 parts (6′ each) (See fig. 11.2) This instrument can be seen by the visitors at first sight while entering the Mandira.

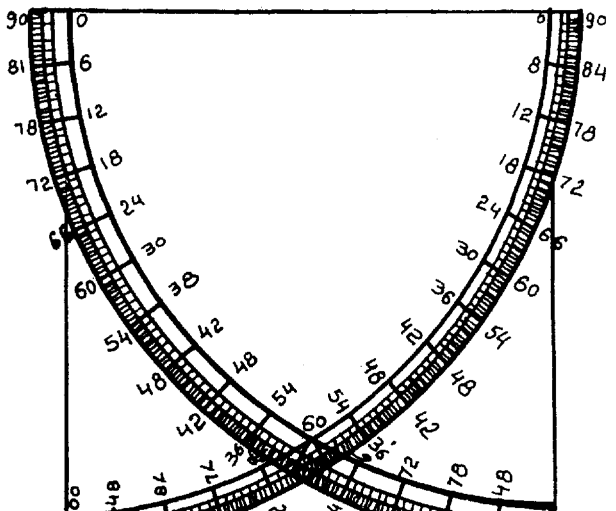


Fig. 11.2

In this instrument every day at midday time when the Sun is on the meridian, the shadow of gnomon falls on the quadrant, whose centre is the former. From the root of the other gnomon upto the shadow are the altitude degrees and from the bottom (upto the shadow) are the co-altitude degrees. But in Varanasi the latitude is more than the maximum declination (the obliquity) of the Sun. So it can not go

higher (towards north) than the zenith there. Thus for the Sun, only the quadrant with centre towards south is useful. Here the graduations of both the north-south (gnomon)-centred quadrants are for the observations of all the stars north or south of zenith, when they are on the meridian.

With the help of this instrument one can easily know the latitude of place and the maximum declination of the Sun. Go on observing the zenith distances every day throughout the year. Note the maximum and minimum zenith distances ($Z_{\xi ax}$ and Z_{mux} (Say)) then the obliquity of ecliptic ϵ (i.e. the maximum declination) is given by

$$\epsilon = \frac{Z\ Z_{max} - E_{min}}{2} \tag{1}$$

Jai Singh performed these observations and found the value $\epsilon = 23°28'$ a value very much accurate in comparison with the value 24° as accepted by all earlier siddhāntic texts. Even the value 23°35' as found by Mahendra Suri using astrolabe in 14th century was not accepted. Now the latitude of the place of observation θ can be found very easiy

$$\theta = Z_{max} - \epsilon = Z_{min} + \epsilon \tag{2}$$

Once the ldtitude of the place and obliquity of the eclipuic are known, one can know the declination of the Sun on any desired day. One can directly note the zenith distance Z, at mid-day time; the declination of the Sun δ will be given by

$$\delta = Z \sim \phi$$

Knowing the declination, the longitude of the Sun can be computed.

It may be pointed out that this instrument can also give the zenith distance for Moon on the days when shadow of the gnomon is visible in moon-light. This way the declination of the Moon too could be determined easily. The maximum declination and hence the latitude too could be estimated by selecting proper days for the observations. For stars too this instrument was utilized to determine zenith distances at transit time and hence the declinations. In this case one had to view the star in line with edge of gnomon and see where the line cuts the graduation on the quadrant. In fact the naked eye sighting lacks precision. Still, the declinations of stars were determined and catalogues were prepared using this instrument.

2. *Some unknown instruments*

Towards east of this Yâmyottara yantra there is an adjacent plane with breadth equal to that of the wall and length equal to seven hands. Although it was initially levelled like water (surface) but now it is uneven. On this plane there were fixed two pegs of iron with holes at the top. These are fixed along eastern direction determined by the two gnomons in the wall. At present only one of them in the east exists there. Quite near this plane there is a levelled circular plane made up of lime bricks and with diameter equal to 1 hand and 9 *angulas*. There is also another levelled circular plane made up of stones and having diameter equal to 2 hands and 7 *angulas*.

Near this plane there is a levelled square with side equal to 1 hand and 11 *angulas*. The graduations on these two circular platforms and the square are erased now. But it seems that earlier these were made to determine the gnomonic shadow and the azimuth.

The use[36] of this construction was not clear to Shri Bapudeva śāstrī. It appears that this horizontal plane was used for determining time and zenith distances etc. during the day. Probably, there was only one gnomon and not two as con jectured by Bapudeva vāstrī. It is clear that the Bhitti-yantra is useful for determining the zenith distances at transits only. Before transiting the meridian, the vertical gnomon could be used to determine zenith distances, hour angles etc. The *Bhitti-yantra* has horizontal gnomons, while the horizontal plane had vertical gnomon(s). The plane could be used for all times during the day. The *Bhitti-yantra* with horizontal gnomon(s) could give only the zenith distances at transits, latitude of the place of observation and the declinations but not the time. On the other hand, the vertical gnomon on the horizontal plane could furnish additional information about time. Although latitude, zenith distance etc. can be determined with the vertical gnomon too, the *Bhitti-yantra* has its special merits in that it gives the zenith distance directly and, if used daily, can furnish quite accurate values of declination of the Sun and the latitude of the place of observation.

There were also two circles and a square. This construction too is quite confusing. It appears that circles were drawn for observing the planets or the stars at the time of their rising or setting, to know the azimuthal angle at that time. Circles could also be used to observe the Sun every day at the time of rising or setting and thus determine the declination and the length of the tropical solar year. A stick or a tube through the centre of the circle was used to record the position of the celestial body on the horizon. Such experiments are discussed in *Sūrya-prajñapti* (as also shown in Fig. 11.1) and also later by Bhāsdkarācārya and others. Probably, earlier, the circle had a smaller size, and so another bigger circle was drawn to get more accurate results. The square structure seems to be the result of drawing north-south and east-west lines as reference lines for the para llel directions. Probably, this square was circumscribed by a circle which was used for the observations on the horizon. We can not think of any other feasible explanation for all of them as a single unit or composite instrument but there is no doubt these were *Śulba-sūtra* like devices for observing achronical risings of stars etc.

3. *Yantra Samrāṭ*

Towards north of the Bhitti-yantra somewhat in the eastern part there is another big instrument called Yantra Samrāṭ. This has a gnomon wall which is set in the precisely determined north south direction and is made up of limebrick stones. This is 3 hands in thickness and 24 hands in length. Its upper part is slanting, made up of stones and points towards Polaris. In the south the root side is 4½ hands in height and on the front side in the north it is 15 hands less 3 *aṅgulas* in height. It has ladders in between. On the eastern and western sides there are two stony arcs with radii 6

hands and somewhat more than a quadrant each in size. These have breadth somewhat less than 4 hands and their thickness is $9\frac{1}{2}$ *aṅgulas*. Their centres lie on the *śankupālis* (the edges of the gnomon wall). On each arc there are quadrants which on edges have divisions in 15 equal *ghaṭis*. Each division is further graduated in uniform six subdivisions which are somewhat less than an *angula* in measure. On the *śankupālis* (on both edges of the gnomon wall) there are two small iron rings, whose centres coincide with the centres of the *cāpa-pālis* (the edges of the arcs). In this instrument, during day time, from the root of the gnomon upto the shadow on the *cāpa-pāli* (in units of *ghaṭi*-timings or the *nata-ghaṭis*). If the shadow of the gnomon falls on the western side then take these (*nata-ghaṭis)* to be the time left for midday and if the shadow falls on the eastern side then take these to be the time past midday. In order to see keenly the shadow from nearby positions there are made stony ridin passages on both the arcs. But now because of excecessive weights, the arcs are little inclined from the actual positions near the terminal edges. So in these parts the sha dow gives time which is somewhat erroneous.

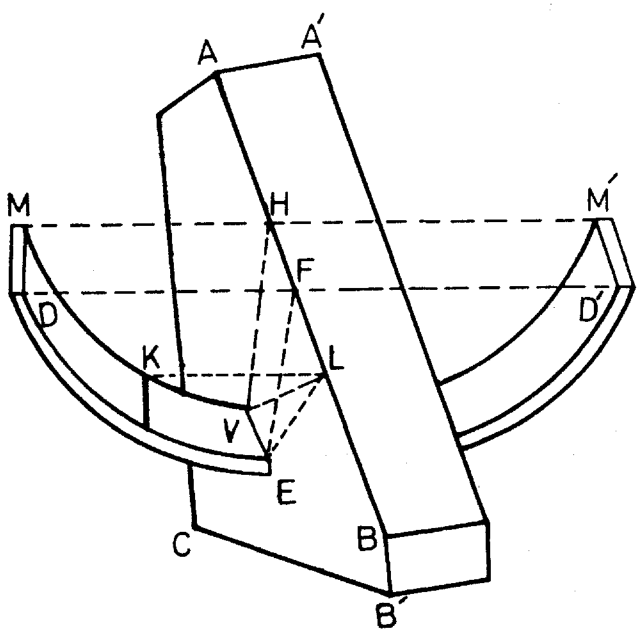


Fig. 11.3.

These shadow of the *śaākupnli* from the Moon is not so clear as it is from the Sun. Moreover the planets and stars do not produce shadow at all, so how the hour angles of the planets Mars etc. and those of stars can be determined with the help of this instrument ? For the here we give the method:

Construct a fine, narrow and exactly straight tube from a metal. Place one of its ends on the edge of the arc and the other end on the *śaṅkupāli* in such a way so that the planet or the star whose hour angle is to be determined is visible through the hole

of the tube by placing the eye below a *cāpapāli*. This way from the point of contact of the tube on the *cāpapāli* the hour angle is evidently determined. From the point of contact of the tube with the *śanku-pāli* upto the centre of the *cāpa-pāli* is the tangent line of the declination of the planet or the star. In Fig. 11.3 the Samrāṭ Yantra is shown. Here L is the point where the tube touches the *śaṅku-pāli* and H is the centre of *śaṅkupāli* where there is the iron ring. The other end of the tube is at K. LH is the tangent line of declination (δ) of the star. VH is the radius of the circles V AB, L HLL$= \delta$. It is clear that the reading of the point K gives the hour angle. It is clear that the declination δ is given by

$$\delta = \tan^1 \frac{LH}{VL}.$$

It may also be remarked that the author of this text[35] claims that Sawai Jai Singh using that big masonary *Bhitti yantra* determined the obliquity of ecliptic to be 23°28′ which is very much accurate a value in comparison with the values prevalent in the literature and accepted by astronomers at that time. It may be pointed out that Sawai's Bhitti yantra being a big scale instrument could yield so accurate a value, better than even the Bhitti yantra of Prof. Flamsteed (1st Royal astronomer of England) in Greenwich could furnish at that time.

In order to find the *viṣuvakāla* (right ascension expressed in units of time) of a star with the help of Samrāṭ Yantra proceed as follows :

1. At the time of sun-set note down the hour angle H'_s of the Sun and after sun-set note down the time t, the star X takes to be just visible. In the diagram (Fig. 11.4) S_2 and S_2 are the positions of Sun on its diurnal path at the time of setting and at the time of star being visible. (The diurnal path of the Sun is not shown here).

Here in fact t must include also the angle traversed by the Sun due to its apparent motion during this time. γ is the vernal equinox, P is the pole of celestial equator and PM is the meridian of the place of observation, D is the culminating point of ecliptic (intersection of ecliptic with the meridian towards zenith side). D is usually referred to as *daśama-lagna* in the traditional Indian astronomical terminology.

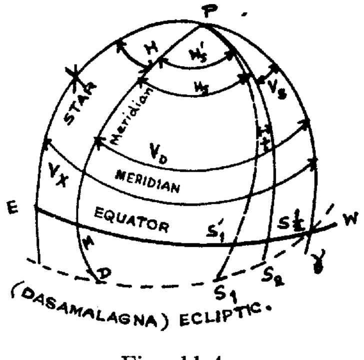


Fig. 11.4

At the time of observation of the star, the hour angle of the sun $H_s = H'_s + t$.

Also *viṣuvakāla* of the Sun $= V_s$.

Thus the *viṣuvakāla* of the *daśama-lagna* is $V_D = V_s + H_s$.

If the hour angle of the star X is measured to be H then it is evident that

The *viṣuvakāla* of the star $V_X = V_D \pm H$.

It is clear that if the star is towards west of *daśama-lagna* then H is to be subtracted from V_D. Thus knowning the *viśuvakāla,* one can convert it to degrees to get right ascension of the star.

4. *Nāḍi-maṇḍala (Equinoctial circle)*

There is set another stony instrument called Nāḍī-maṇḍala towards eastern direction. Its plane lies in the plane of equator. On northern side of it there is made a circle, whose diameter is 3 hands and 2 *aṅgulas.* It is divided in four parts by vertical and horizontal lines. In each quadrant there are graduated 90 degrees. At the centre of this circle there is an iron peg pointing towards the Polaris. From the shadow of this rod, when the Sun or the *nakṣatra* is in the northern hemisphere, its hour angle is known. Also the south-facing side of this instrument has a circle with diameter equal to 1 hand and 13 *aṅgulas.* This too like the north-facing side is divided into quadrants by vertical and horizontal lines and graduated in degrees. This circle is to know the hour angle of the *nakṣatra* or the Sun in the southern hemisphere.

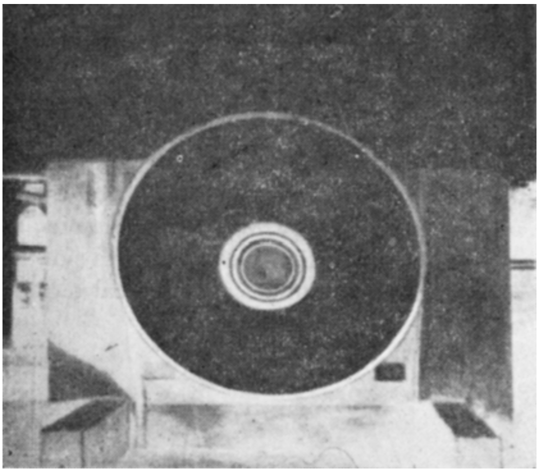


Fig. 11.5. *Nāḍ-maṇḍala*

5. *Cakra-yantra*

Near this very instrument there is Cakra yantra. It lies in between two walls. It is made of iron and is capable of rotating. On the outer periphery, there is covering with pittal-foil. Its diameter is towards Polaris. The periphery is 3 *aṅgulas* broad and

$\frac{1}{2}$ *aṅgula* in thickness. On edges it is graduated in degrees and each degree is further divided into four equal parts. There is a *paṭṭi* (tube device) made up of pittal. It is 3 *aṅgulas* broad and passes through the peg at the centre. The same has a thread with a mark (Index) in the middle.

To know the declination of a planet or star with the help of this, move the instrument and the *paṭṭi* in such a way that the celestial body, whose declination is to be determined is visible along the thread to the eye placed below the *paṭṭi*. From the diameter perpendicular to the one facing the pole, the degrees on the periphery upto the *paṭṭi* is the declination of the planet or the star.

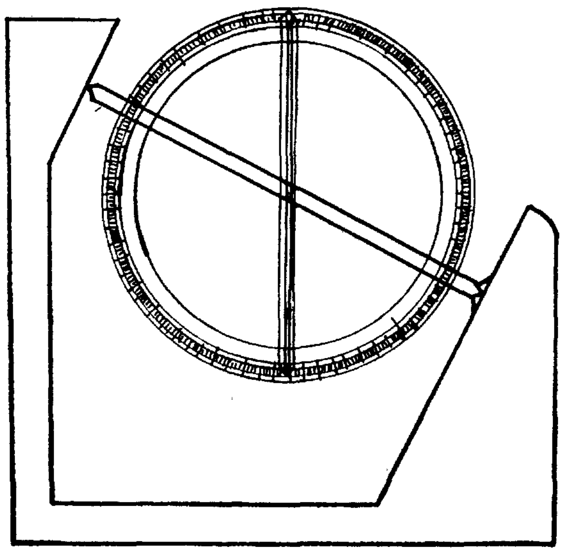


Fig. 11.6

In this very instrument there were base circles etc. for determining hour angles of planets and stars, but these have been erased now. The *paṭṭi* is bent so with the help of this as described above, the declination can not be determined correctly. This instrument is somewhat similar to meridian circle or transit instrument of present times, which is fitted with a telescope instead of a Vedha *paṭṭi* and is set always in meridian for observations at transits only.

As has been already remarked, there exists an English version of the Kāśī Mānamandira Vedhālaya Varṇanam by Bāpudeva Śāstri. It has some more or somewhat different details.[37] In the discussion of Cakra-yantra more information is given in the English exposition indicating that the breadth of the circle was 2 feet and 1 inch thick, faced with a plate of brass 3/10 inches in thickness. Thus, there are more or somewhat different details in the English exposition. Probably, the English exposition was written later, having measured the dimensions more precisely, but the date of compilation of first edition of the English text is not known.

Now, let us come to those points which are not clarified by Bāpudeva śāstrī. In the discussion on Cakra-yantra he has mentioned that there were some base circle which were lost or broken. These circles were provided with this instrument in order to determine the hour angles etc. of planets and stars. Probably, they were the meridian and the equator with proper graduations. It is clear that the reading on the equator from its point of contact with the meridian upto the *paṭṭi* pointing towards the celestial body gives the hour angle. Another possibility is that there might have been the *kṣitija* (the horizontal circle of the place) and the equator. In this case the angle between the *paṭṭi* (index) and the horizontal circle is the complement of the hour angle.

6. *Digaṃśa yantra*

On the eastern side of this instrument there is a big Digaṃśa yantra (an instrument for knowing diagaṃśa or azimuthal angle). At its middle there is a pillar having diameter equal to two hands and 10 *aṅgulas* and height equal to $2\frac{3}{4}$ hands. At its centre there is fixed a gnomon with a hole at its bottom (see Fig. 11.7). From this pillar at a distance of five hands minus four *aṅgulas* there is an enclosing (circular) wall. Its height is equal to that of the pillar and thickness is one hand. From this wall too somewhat more than 2 hands away towards the outer side there is another enclosing wall. Its height is double that of the first one and the breadth is $1\frac{1}{3}$ hands. The upper sides of both the walls are graduated in directions and degrees. On the outer wall there are pivoted iron pegs in the four directions.

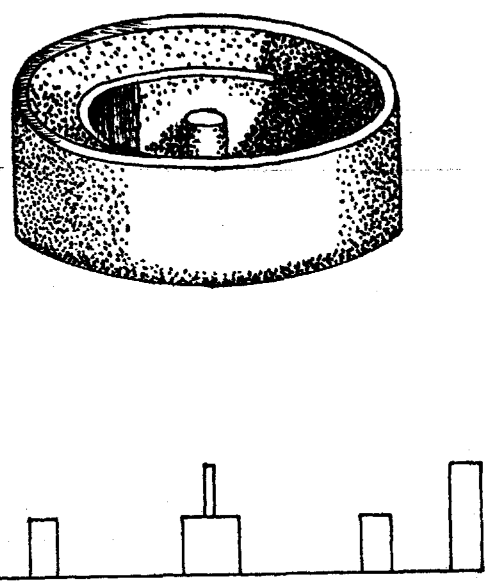


Fig. 11.7

The instrument of this type is used to find the azimuth. A thread is fastened to the eastern and western pegs and another one to the similar pegs fixed at the north

and the south points. The two threads intersect at the centre of the pillar in the middle. Then a third thread is fastened tight to the centre at the pillar, the other end of this straightened thread is moved in such a way that the planet whose azimuth is to be determined and the intersection of the two threads are along the third thread as seep by placing eye on the outer edge of the middle wall. This way the azimuth of the planet is the angle measuring as many degrees as there are on the edge of the outer wall from the east or west point upto the third thread.

Besides these there is another small Bhitti yantra and a small Samrāṭ yantra.[38] There was another Nāḍī-maṇḍala which is not mentioned in the Sanskrit text but is described in the English exposition by Bapudeva Śāstrī. Also there was a big quadrant—Turīya yantra made up of massive stone with very precise fine graduations. Burrow witnessed and praised the workmanship in the 18th century.[39] This instrument is not at all mentioned by Bāpudeva Śāstrī. Where has it gone now? No one knows. These are the only instruments which we have come to know of in Māna mandira observatory of Kāsī.

Ujjain Observatory

In Ujjain observatory there are the following instruments of the above type: (a) Samrāṭ yantra; (b) Nāḍīvalaya yantra; (c) Digaṃśa yantra; and (d) Yāmyottitarabhittiya yantra.

Digaṃśa yantra is in ruined condition. In Nāḍīvalaya yantra the graduations are in bad condition. Samrāṭ yantra is also in skeleton. In Yāmyottara-bhitti yantra too, the graduations have disappeared. The *bhitti* is inclined at 5° to the vertical and is much dilapidated. There is a flight of steps leading to narrow platform at the top. The constructions of this yantra and other yantras are basically the same as in Varanasi, although the dimensions differ.

Delhi Observatory

In Delhi, there are mainly the following instruments:

(1) It is Samrāṭyantra similar to the one in Varanasi but has also a Saṣṭāṃśa yantra which is a large graduated arc of 60°, built in the plane of the meridian. Through an orifice, Sun while transiting the meridian, shines on the arc indicating its meidian altitude. At the top of the triangular gnomon there was a circular pillar which was used for rough azimuth observations but now there is a small Sundial. Before 1910 A.D. there was only a pillar as evidenced from Daniel's drawings.[40]

(2) *Jai Prakōśa yantra*

The observatory of Kaśī has no Jai Prakāśa yantra and Rāma yantra which too were the inventions by Mahārājā Jai Singh. Delhi observatory has these instruments. Here we give the details of Jai Prakāśa yantra[41] which was called Crest Jewel or Yantra śiromaṇi by Pandit Samrāṭ Jagannātha. This is an armillary sphere cut into two by planes of the horizon. Only the upper part being kept as it is the only portion

visible to us. It consists of a concave hemisphere dug in the ground (See Fig. 11.8). The rim represents the horizon of the place of observation and is graduated in degrees and minutes. Here *EW* and *NS* are east-west and north-south lines. *NPS* is the meridian passing through the zenith of the place of observation and the north south points. Here *P* represents the south. With *P* as centre and radii $\pi/3 \pm \epsilon$ (ϵ being obliquity of the ecliptic) draw two circles. These will evidently represent the circles described by the ecliptic around the pole. Both these aie marked in signs *(rāśis)* degrees minutes and second. On these circles mark points indicating position of 12 *rāśis* representing their rising from west to east. Taking these as centre draw 12 circles which will represent 12 positions of the Sun in *rāśis* on the ecliptic. With the lowest point of the hemisphere as centre and spherical radii 6°, 12°, 18°,.., 90° describe 15 circles, the lowest one being the horizon. Through *O* draw sixty circles of azimuth and a hole is made at the lowermost bottom point of the bowl. The rays of the Sun fall through this hole inside the hemisphere and revolve as the Sun describes diurnal motion. At all instants its position can be directly read from the graduations. In the hemisphere, the paths are dug out for observer to go inside the hemisphere for taking readings. Since the dug portions can not have graduations, there is made another complementary hemisphere in which the part dug in the 1st hemisphere is not dug, instead have graduations and whichever parts are graduated in 1st one, are dug in the second hemisphere. Thus with the help of two complementary hemispheres, position can be read for any instant. The duplicate Jai Prakāśa yantras in Delhi and Jaipur have five passagese each.

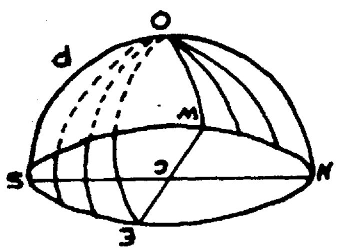


Fig. 11. 8.

G. R. Kaye[42] has speculated Berosus' Bowl to be the basis of Jai Prakāśa yantra. L. V. Gurjar[43] has contradicted his view and proved the same to be baseless arguing that Berosus (A priest at Bel in Babylon) is not accredited with any invention of Bowl-like device. He (Kaye) himself accepts that the Berosus' Bowl was not fully graduated and may be Jai Singh never knew of it and developed Jai Prākāśa yantra independently. In fact Jai Prakāśa yantra originated from Armillary sphere described in *Sūrya-siddhānta, Siddhānta S'iromaṇi* and other texts of Indian Astronomical tradition.

3. *Rāma yantra*

This consists of a cylindrical vertical graduated wall of diameter 24 feet and 6 inches[44] and a vertical pillar at the centre. The wall and the floor are graduated. The wall is cut in between, for fixing rods in order to have observations of stars (see

fig. 11.9). There is another complementary identical Rāma yantra which differs from the first one in graduated and cut passage portions of the wall. This instrument gives altitudes and azimuth of planets and stars.

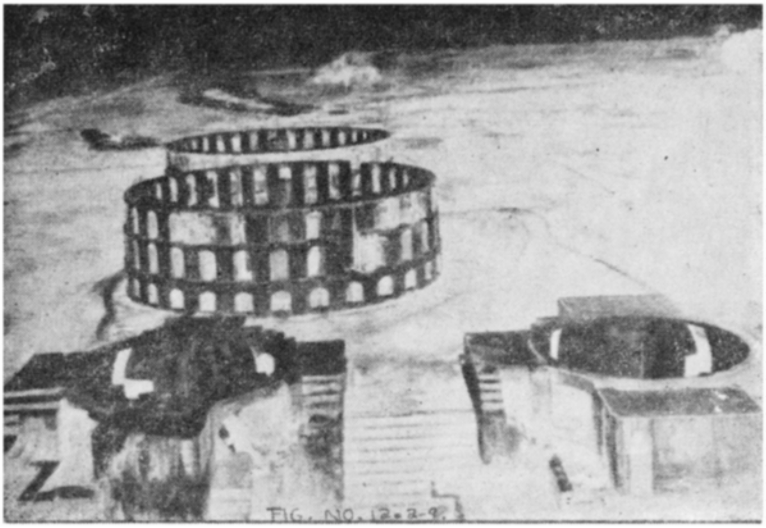


Fig. 11.9. Rāma Yantra

(4) *Miśra-yantra*

It consists of a Samrāṭ yantra-like structure, which has towards east and west side of triangular gnomon two or more non-horizontal half circles instead of quadrant arcs in horizontal plane. (Fig. 11.10.) These semicircles are inclined to the plane of the Delhi meridian at angles approximately 77° and 68½° east and west, one semicircle being in the meridian of Greenwhich and the other in the meridian of Zurich (Germany). Thus, even sitting in Delhi one can perform Samrāṭ yantra experiments for Greenwich and Zurich also.

Besides these, in Delhi Jantar Mantar there is a Bhitti yantra similar to the one in Kāśī Māna-mandira. The north wall of Miśra yantra is inclined to the vertical at ap angle of 5° and is marked with a large graduated circle. This is called Karka rāśi-valaya (i.e. circle of sign of Cancer). Latitude of Delhi is 28°28′. Since the obliquity is almost 5° less than this, so when Sun enters *sāyana* (tropical) Cancer, it will shine over the north wall for a short period and the shadow of the central pin fitted there falls on the graduated circle; which indicates *sāyana karka-saṃkrānti* (transit of Sun in tropical Cancer). There was one quadrant also, which is no more now.

Jaipur Observatory

In Jaipur, the collection has a Samrāṭ yantra, Ṣaṣṭyaṃśa yantra, Rās'i-valaya yantra, Jai Prakāśa yantra, Kapāla yantra, Rāmayantra, Digaṃśa yantra, Nāḍī-

valaya yantra, Yāmyottara-bhitti yantra, two big astrolabes, a Unnatāṃśa yantra, Cakra-yantra, Dhruvadarśaka yantra, and a Krānti-vṛtta-yantra of 17.5 feet diameter.

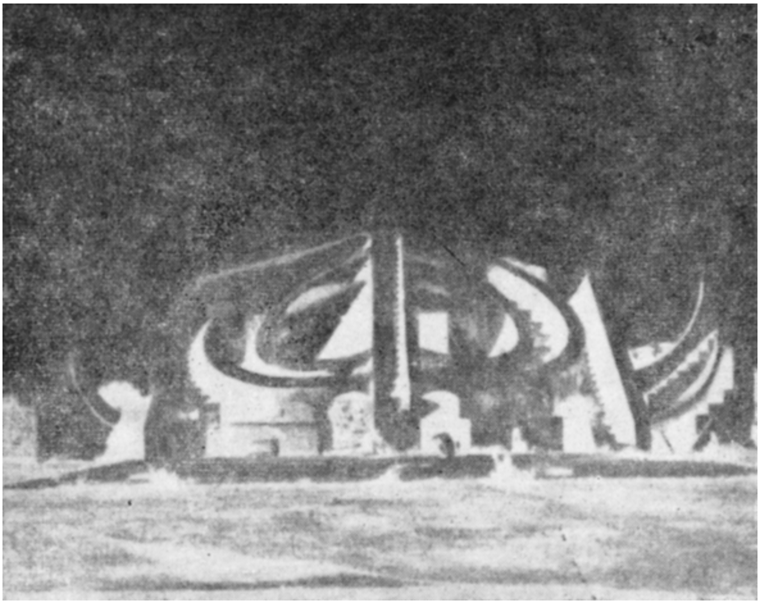


Fig. 11.10. Misra Yantra

Rāśi-valaya-yantra is a combination of 12 Samrāṭ-yantra-like structure one for each *rāśi* (sign). The cylindrical wall is not in the equatorial plane; instead it is in the plane of the respective *rāśi*. Kapāla yantra is a hemispherical bowl similar to the Jai Prakāśa yantra but it is used for studying rising *rāśi*s, knowing time, azimuth, longitude, *lagna* etc.[45] Unnatāṃśa-yantra (altitude instrument) is made up of metal and is used to determine altitudes of heavenly bodies. In Jaipur observatory it is made up of circular metal of 18 ft diameter graduated to 1/10th parts of a degree. The circle can be rotated about its vertical diameter. A pointer was attached to a hole at its centre. The instrument is fixed at an elevation so that readings can be taken by standing at any point. Dhruva-darśaka yantra is a triangular gnomon of sand stone with elevation=27°. The north face is at right angles to the base. Such an instrument was a big help to astronomers, navigators in determining directions, in setting instruments and in knowing local mean time with the help of *dhruva-matsya* (polar fish). Garret et al.[46] described all instruments in Jaipur observatory with good drawings in details.

Krānti-vṛtta

This was an instrument which could give celestial longitudes and latitudes of heavenly bodies directly. It consists of a masonary pillar with north face fitted with a circular stone in the plane of equator (see fig. 11.11). There is a brass pin *P*

at its centre to which a metal frame work is attached. The metal frame consists of two inclined brass circles *APB* and *BQA'* which represent equator and ecliptic which was taken to be 23°27′ at that time.[47] The metal frame work can be rotated around the pin *P* and the angle of rotation can be measured by a pointer moving over the circumference of the circular stone graduated in signs degrees and minutes. The ecliptic circle is fitted with two quadrants at right angles to the plane of *BQA'* with a bar whose centre passes through a pin at *Q*. The bar *AA'* can be rotated freely about *Q*. The two quadrants too can rotate about the bar *BA'*. These are graduated in degrees and minutes and fitted with sighting bars. Note that *AA'* points towards solstices. The quadrant at *A'*, when rotated to see the heavenly body with the help of the sighting rod makes a certain angle α with *AA'*. Then $90+\alpha$ or $90°-\alpha$ gives the longitude and the sighting bar gives the latitude. This instrument is found in dilapidated condition in Jaipur observatory.

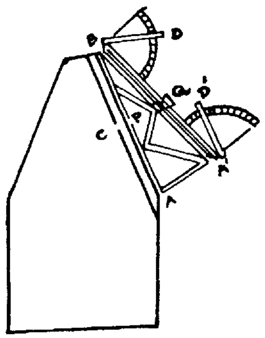


Fig. 11.11.

Astrolabes

In addition to the instruments discussed in the previous sections, we also find astrolabes of different sizes in repositories of Sawai Jai Singh's observatories. Earlier Mahendra Guru (A.D. 1370) wrote a text on the subject "Yantra-rāja"[48]. It is believed that Arabs developed astrolabes but there is no doubt that several excelleent astrolabes of improved designs were produced in India after the tradition of Central and West Asia.

(I) The principle of construction of this sophisticated instrument is based on stereographic projection of celestial circles on a plane. This is a conformal mapping in which angles are preserved. All circles on the sphere project into circles except those which pass through the point of projection, latter ones project into straight lines. Astrolabe is generally made up of a metal plate on which two perpendicular diameters are carved. In the figure given below (Fig. 11.12) there are *SN* and *EW* representing the south-north and east-west directions. The circle *NWSE* with centre *C* is taken to represent the circle of tropic of Capricorn. Take a point *P* such that $\angle SCP = \epsilon$ = the obliquity of ecliptic. Join *CP* and *EP* cutting *CS* in *X*. With *C* as centre and *CX* as radius, draw a circle, which will represent equator. If Υ is the point of intersection of this with *CP* and *A* with *WE*, join *A* and Υ cutting *CS* in *V*,

With C as centre and radius$=CV$ describe a circle. This circle will stand for tropic of Cancer.

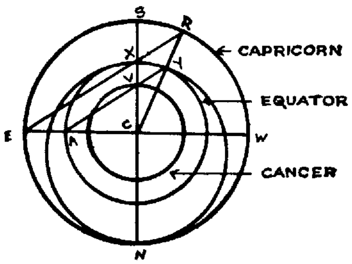


Fig. 11.12. (a)

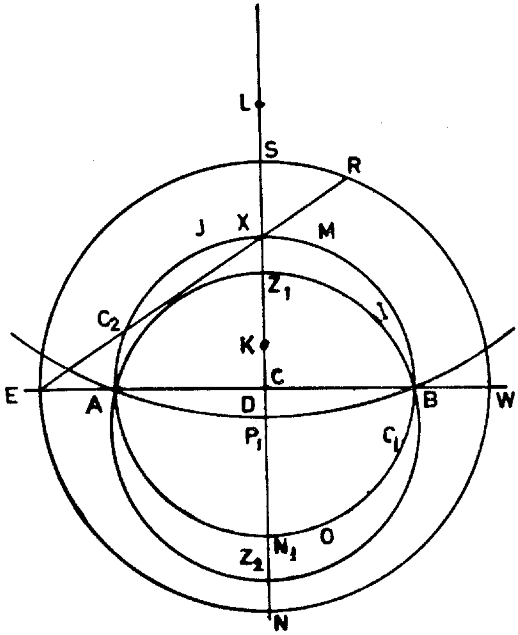


Fig. 11.12 (b)

Let us see how the other circles can be drawn using the basic three properties[49] of stereographic projection. Here all the drawings could not be plotted in the figure but one can understand the details of drawings from the following :

(II) Let B be the point of intersection of EW and equatorial circle.[50]. Let $BC=\theta$ the latitude of the place towards north. Join AC, cutting NS in P_1 (say the point P^1 is called first point). Take an arc $AC=\theta$, so that C_2 is diametrically opposite to C_2. Join AC_2 cutting NS in P_2 (Say). The point P_2 is called second point. On P_2P_2 as diameter, draw a circle which will represent the horizon of the place of observation.

(III) To draw parallel of altitude a, take $C_1I=a$, towards S, and point J so that $C_2J=C_1I$. Join AI and AJ cutting NS in K and L respectively. On LK as diameter draw a circle which will represent the parallel of altitude.

If $AC=r_a$ then it can be shown that the radius r of the parallel of altitude 'a' is given by :

(using the projection geometry)

$$r_a = \frac{1}{2}\, LK = \frac{r \cos a}{(\sin \theta + \sin a)}$$

The mid point of IK will be the zenith of the place of observa tion,

(IV) To draw prime vertical, take arc $XM=\theta$ towards W. Join AM cutting at Z_1. If N_1 is the point, where equator cuts NS, take arc $N_1C=\theta$. Join C_1C, produce it to meet NS in Z_1. The circle drawn with diameter Z_1Z_2 will be the prime vertical.

It can be shown that

$Z_1Z_2=2\ r_e$ sed θ.

Thus the radius of the prime vertical is r_e sec θ Angle is θ the point is P_1 (Fig. 11.12(b)). Here P_1, is the centre of prime vertical, and $CP_1 = r_e \tan\theta$.

(V) Since the latitude of the place is equal to the declination of its zenith, the lines joining intersections of horizon and NS with he divisions of equator will give us graduations of the prime vertical.

(VI) To draw *digvalayas* (azimuth circles) draw circles through graduations of horizon, zenith and nâdir. The centres of all such circles will lie on a line through P_1 and parallel to EW. If $Z_1\ RZ_2$ be one of the azimuth circles corresponding to the azimuth angle A and C' be its centre then $\angle OC\ Z_1 = A$. The distance of the centre C' from Z_1 is

$$C'Z_1 = r_e\ s_e\ c\ \theta \text{ cosec } A.$$

(VII) In order to draw hour circles make equal divisions of tropics of capricorn and cancer and equator. Mark these (1), (2), (3)....(12) on each of these with (1) of equator as centre draw a circle (α_1) through (1) of Cancer and with (1) of Capricorn as centre and same radius draw another circle (β_1) to cut (α_1). Take (1) of cancer and same radius draw a circle (γ_1). The lines joining the points of intersection (α_1), (β_1) and (γ_1) will intersect at a point which is the centre of 1st hour circle. With this as centre draw a circle through (1) of the tropics and equator. This is the 1st hour circle. Similarly all the twelve circles can be drawn.

(VIII) The equator can be graduated in regular hours (=1/24th of a day) divisions by dividing the same in equal parts and drawing 24 radiating straight lines from pole to the points of divisions.

(IX) It can be shown that in this mapping diameter of ecliptic= $\dfrac{r_e^2}{r_c} + \gamma_c$

where r_e and r_c are radii of equator and tropic of capricorn. In the figure VN is the of the ecliptic. Within this the circles are to be drawn as discussed above. Such a diameter disc is to be taken and to be pivoted at the pole as the ecliptic. One thread passing through the pole of the ecliptic ($\epsilon=23°$—27 from pole along the meridian) with its other end moving on the graduations, gives the divisions on the ecliptic wherever it cuts the ecliptic.

Knowing the ecliptic and equatorial coordinates of planets and stars, their positions can be fixed on the disc. From east point towards north-south of equator mark a point at angular distance equal to the declination of the celestial body. Join

it to the south of equator. Mark its intersection with EW (produced if necessary) as 'I'. Describe a circle with pole as centre and radius=distance between pole and the point I. This is the ecliptic, indicating its ecliptic distance from nearest equinox. Join pole and this point, wherever this line cuts the parallel of declination, is the position of the celestial body.

Alternatively one also uses horizon at 66°33′ N and digvalayas. This horizon is the ecliptic and the digvalayas are great circles passing through the pole of ecliptic. Mark the celestial latitude on the perpendicular circle which passes through graduation, representing the position of the body on the ecliptic. This point is the position of the body.

This instrument serves the purpose of solving problems involving relations between azimuth, altitude, latitude, longitude time and positions in a very handy way. At its back is fitted a sighting bar with which only the altitude is to be noted. Using only this single observation, the instrument serves as a calculator like a slide rule.

There is no doubt that such instruments are common in India and Arab countries, but the accuracy and ease in Jai Singh's designs of astrolabes was remarkable. Yantra rāja of Jai Singh is not found in any collection of astrolabes in foreign museums. One has to study the available literature on the topic, for any conclusive inferences regarding the originality of the Hindus in the field of astrolabe-making.[51]

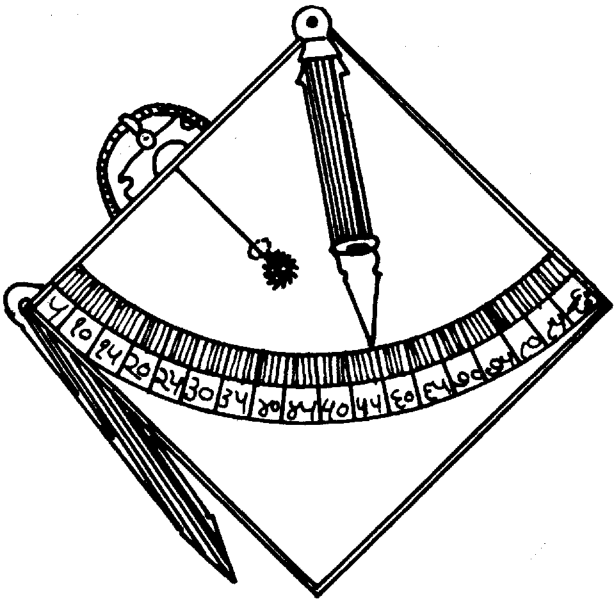
It may be pointed out that there are available some astrolabes in Arabic and also in Devanāgari script. The astrolabes of Jai Singh Sawai are preserved in Jaipur observatory. Probably the astrolabes of Delhi observatory might have been removed to Jaipur or some other place at the time of invasion by Nadir in 1739 A.D. There is no doubt that the collection does not have all astrolabes of Jai Singh Sawai. The number of such astrolabes in Devanāgari was more than thirteen.ı[52] R. Burrow in 1790 A.D. witnessed an astroiabe in Devanagari which is not avallable now.[53] Also G. R. Kaye was shown some brass astrolabes prepared under the scholarship of Sh. Jai Singh Sawai. In 1864 in Lahore exhibition there were some astrolabes from Kapurthaia.[54] The museum at Caicutta and Lahore had astrolabes in Devanāgari in eariy 20th century. Thus we believe, that there were quite many astrolabes in Devanāgarī script. Jaipur collection has astrolabe of Shah Jahan's time (dated A.D.) 1657 and astrolabe of the time of Aurangzeb (dated A.D.) 1680 This collection has two big astrolabes. In Red Fort museum at Delhi there are few astrolabes. One astrolabe is dated 16th A.D. the other one of 1637 A.D. made by Mr Muhammad Mukhim, grandson of Shekha Alla-Hadadi son of Mr Mulla Isa of Lahore. In Indian traditional astrolabes important parts referred to are :—(1) *Akṣapatra* which differs from latitude to latitude. (2) *Bhapatra* which is same for all places. In two of the astrolabes of Jai Singh, there are 7 akṣapatras on both sides for latitudes from Delhi to Kashmir. In one of the astrolabes there is no *bhapatra* and one has to rotate the *vedhapaṭṭi* conjoint with ecliptic. Thus this one is of inferior type as regards its operation. In the

other ones, the pointer can directly tell *daśamalagna* etc. The astrolabes of Arabic origin too have in general both the plates. (See fig. 11.13).

Fig- 11.13,

In Devanâgari characters, there are *laṅkodayas* (intervals for rising of signs) engraved on *bhapatra* which are characteristics of Indian tradition. Also there are 27 asterisms in Sanskrit names. These markings are in Indian traditional style, and differ from Arabic or Persian engravings on astrolabes, preserved in American Institute of Researches on History of Science in Cairo and in Museum at Greenwich.

The 48 divisions of sky were used by Ptolemy but the astrolabes of Jai Singh use as many as 108 divisions like Arabic astrolabes. Sh. Sawai Jai Singh corrected the positions of 1029 stars which were quite accurate according to the standards of those times but not so accurate as in Nautical Almanac these daye. It may be remarked that Shri Jai Singh used Indian *ayanāṃśa* (angle of precession) of *Sūrya-siddhanta* unlike the Arabic traditions of Ptolemic origin. The value of *ayanāṃśa* used is 23° as it appeared but it could not be decided finally. In spite of all these deviations, the astrolabes of Sawai Jai Singh were flat astrolabes (Astrolabium planisphaerum or zat-al-safaih). These have thin discs (tablets) marked with *digaṃśas* (azimuths) *nata-vṛttas* (hour circles) etc. The *chunchu* (pointer) (See fig. 11.14) and the graduated circle form the important parts used in observatories while the tablets and rotating *aṅkabut* the graduated circle etc. form an efficient machine which differs much in details in Arabic and Indian astrolabes. The observational parts do not differ much. The markings on the circles in Hindu astrolabes are as in Muslim ones in general, but the large astrolabes of Jaipur have finer graduations.



gig. 11.14.

It is to be pointed out that Indian astrolabes do have their specialities in markings (like in *laṅkodayas* rising of signs etc.) and different styles in workmanship. For comparison all astrolabes of essentially Hindu tradition must be studied for final conclusions. It may be remarked that in India there are no astrolabes of much antiquity available anywhere. Even we do not find astrolabes of the times of Mahendra Suri or other authorities on astrolabe-making before the time of Jai Singh. The instruments might have been destroyed or taken off during invasions. We do not hope to find any old ones and under these circumstances, the only way is to study the works of Mahendra Suri etc. and compare with the features of astrolabes of Arabic and European origins. Also the comparison of existing instruments in a quantitative fashion will reveal the originality in the features of these instruments.

The observatory at Mathura[55] was located on the banks of Yamunā. Jai Singh Sawāi a staunch devotee of Lord Kṛṣṇa usually visited Mathura and built a temple of Lord Krisṇa. For observatory, he chose a fort built by his ancestor Rāja Māna Singh of Amber (end of 16th century A.D.). Due to attacks by religious fanatics there are not even debris of the Vedhaśālā (observatory) there. This observatory had Laghu-Samrāṭ-yantra, Dhūpa-ghaṭī (Sun dial), Yamyottara-bhitti-yantra (Meridian wall). Here yantras were of smaller size, in comparison with the similar ones in Jaipur. The last remains of the Vedhaśālā were put to oblivion in 1857 A.D. when Jyoti Prasad, a contractor bought the fort and demolished every bit of the Vedhaśālā.

12 INTRODUCTION OF MODERN WESTERN ASTRONOMY IN INDIA DURING 18-19 CENTURIES

S. M. RAZAULLAH ANSARI

INTRODUCTION

ANCIENT INDIAN ASTRONOMY

The great antiquity of astronomical activity in India is quite a well-know fact of history. According to one account[1] astronomical calendar calculations existed presumably as early as the 14th century B.C. Even if one does not agree with this date, it is fairly known today that ancient Indian astronomers were familiar with the calendaric astronomy[2] in the period 1300 B.C. to 300 A.D.[3] In any case it is well-established that Indian calendaric astronomy was developed further into the planetary astronomy in the first few centuries of the Christian era when Sanskrit astronomical treatises, the siddhāntas, were compiled. Out of the five siddhāntas as reviewed by Varāhamihira (6th c. A.D.),[4] a late version of one of them, the *Sūrya-siddhānta* is still extant today.[5] The astronomical tables as compiled in ancient India[6] were therefore based, besides on observation,[7] also on the modified pre-ptolemaic rather Indian epicyclic-eccentric model of the planetary motion as described and further developed in those treatises and their commentaries.[8]

EARLY INDIAN OBSERVATORIES

The history of the establishment of early astronomical observatories[9] in India has not been worked out in detail. The following references may be quoted here from literature.[10]

(i) According to the first Mughal King of India, Bābur (1483—1530), observatories existed in the cities of Ujjain and Dahār. Employing Bābur's remarks the observatory at Ujjain is estimated to be extant in the first century B.C. This period may be an over-estimation, though not impossible. After all Ujjain was the Greenwich of India from ancient times, even known to Greeks as οζηνγ and to West-Asian Islamic astronomers as the cupola of the earth (*qubbatul arḍ*).

(ii) 'Abd Al-Rashīd Al-Yāqutī (15th C.) reported an observatory in the city of Jajili.

(iii) 'Abdullāh Shukrī Al-Qunāwī (16th C.) reported also an observatory at *al-Kankadaz* or *al-Dharkanak*. These cities have not been identified so far, and no

remains of those observatories exist today. We may mention that in the West-Asian astronomical literature, *Kanak-dar* is said to be the location somewhere in the Far East of Arabia corresponding to the "Longitude Zero". One may identify it with Ujjain.

(iv) Maharaja Swai Jai Singh II (1686—1743) of Ambar was commissioned by Emperor Muḥammad Shāh (reign 1719—1748) to build a number of observatories. Jai Singh got constructed five observatories at Delhi (1724/28), Jaipur (1734), Banaras (1737), Ujjain and Mathura[11 12]. The last one is no longer extant. In these observatories are extant even today masonary and metal instruments (of pre-telescopic era), which were constructed according to Ulugh Beg's school of astronomy at Samarqand,[13] as also those which were of Jai Singh's own invention, as claimed by him in *Zīj-i Muḥammad Shāhi* (here-after referred as ZMS, and with folios of Aligarh manuscript). Here, however, we shall not be concerned with that aspect of Jai Singh's astronomy.[14] What is more significant than the above-mentioned instruments is the work of Jai Singh from the standpoint of modern post-telescopic observational astronomy. It is not widely known that Jai Singh *did make use of a telescope and with its help carried out some observations.*

Jai Singh's Reception of European Astronomy

The Use of Telescope

In the text of his *zīj*, Jai Singh clearly states that "telescopes are constructed in my kingdom" and he enumerates the following observations carried out with their help.[15];

(i) the ellipticity of the orbits of the Moon and the Sun;
(ii) the phases of Mercury and Venus;
(iii) the existence of sunspots and their rotation;
(iv) the four satellites of Jupiter;
(v) the ellipsoidal shape of Saturn; and
(vi) the slight motion of the "fixed" stars, with different velocities.

We have compared several manuscripts of ZMS, extant at Tashkent, British Museum Cambridge, Aligarh, Bombay, Jaipur, Lahore, Tonk, Delhi and Bankipore, and have found that in all those manuscripts the above-mentioned particular passage is given. Till to-date in only one manuscript of ZMS[16] that passage is not given. One would like to conjecture that it was copied from the "first" edition of ZMS compiled before 1728—29 when Jai Singh sent an embassy to Portugal ! In fact such a manuscript of ZMS, circa 1727 is supposed to be extant in Sipah Salar Library, Tehran.[17]

As a matter of fact, the use of telescope in the middle of the 18th century for astronomical purpose is hardly surprising, since historical records show that European

telescopes were available in India as early as 17th century. In the first quarter of the seventeenth century, prospectives,[18] i.e. telescopes, were presented to Emperor Jahangir (reigned 1605—27) by Sir Thomas Roe. Thereafter it became a general practice for the Mughal nobility to get telescopes as presents.[19]

It may also be noted that a telescope (*dūrbīn*), as a kind of spectacle used by boatmen and also for reconnaissance of enemy's army, was already known to some Indian compilers of Persian dictionaries of 18—19th centuries.[20] Thus the telescope as a useful instrument was already known in 17th century India and it is of course certain that Jesuit geographers/cartographers used them in India for carrying out astronomical observations. Since Jai Singh had developed close contacts with Jesuits in order to familiarize himself with the European astronomy, he sent in about 1728—29 an embassy of Jesuits and Indian astronomers to the then Portuguese King.[21] It is highly probable that a telescope (besides other astronomical books) should have been presented to Jai Singh by the Jesuits after circa 1730.[22] Consequently like Galileo, Jai Singh was the first Indian to use telescope for *astronomical observations* in India. However, whether he used telescopic observations for the compilation of ZMS is still under study, to be reported elsewhere.[23]

We may also mention here another evidence regarding the use of telescope, namely the diagrams corresponding to the five observations mentioned above. These diagrams (see photograph)[24] have been found by us in a number of manuscripts, for instance the extant one at Lahore, Bombay, Cambridge and Bankipore/Patna, but *not* in the manuscript of British Museum. Only in one of those manuscripts (at Bombay) a selenographic diagram of the lunar surfcce is given. All of these diagrams are on the margins of some folios but not on the folio where the aforementioned five observations are listed.[24]

We would like to digress here for a short while in order to show that some Europeans like Kaye have treated the Asian contribution to science from *Eurocentric* standpoint unobjectively,[25] and consequently have suppressed at times the significant information. This is exactly the case with the use of the telescope by Jai Singh and his six rediscoveries mentioned before. Kaye in his monograph[26] quotes the French translation of Sayid Ahmad Khan's work on monuments of Delhi by Garcin de Tassy in which those rediscoveries are clearly listed. About the observatory *(Jantar Mantar)* at Delhi it is mentioned therein.[27]

> "Dans cet observatoire il n'était pas nécessaire
> de faire le calcul des divers aspects lunaires,
> du lever et du coucher des étoiles et des maisons
> de la lune, parce qu'a l'aide du télescope toutes
> ces choses se voient de jour".

Kaye did not breathe out a single word about the use of telescope by Jai Singh or his rediscoveries. One the contrary, he was of the opinion that Sayid Ahmad's "account is not very reliable", and "Jai Singh's apparent indifference to European achieve-

ments is rather remarkable". A blatant dishonesty on the part of Kaye, who did not forget to mention in footnotes the European innovations: the aerial telescope of La Hire or the first mention of telescopic sights in 1667.[28]

Notwithstanding the above-mentioned use of the telescope by Jai Singh, we do exclude the possibility that he employed the telescope more as a device just for observations (mapping the planetary surface, planetary and star fields) rather than as a measuring instrument, see the photograph. For Jai Singh it was quite natural to verify the famous Galileu's observations, *as it had happened also in Europe.* According to Van Helden,[29]

> "We tend to think that the full potential of the telescope as a research instrument was *immediately* apparent to Galileo and his contemporaries; this was *not* the case. During the first twenty-five years of its existence the telescope remained primarily an instrument for terrestrial use, usually for naval or military purposes. When one turned such an instrument to the heavens, it was *usually to see for oneself the discoveries of Galileo.*"

If therefore "the astronomical telescope was not particularly popular for the first half-century after its invention",[30] and only "between 1650 and 1685 astronomers finally came to realize the full potential of the new instrument", that is, "the telescope become a full-fledged instrument which was used not only for discovery, also for measurement",[31] we can not blame Jai Singh for not compiling his tables with the aid of the telescope; we do not know presently at all as to what kind of telescope "was constructed" by him and which in-built defects existed in his telescopes or those presumably presented to him by the Jesuits.

We would like to recall briefly here the optical problems and other defects in the refractors of the 17th century,[32] in order to understand the historical context in which the general development of telescope took place. In that context one could then try to understand the limited use of the telescope by Jai Singh.

(1) The spherical or chromatic aberrations of the lenses should be mentioned first. Those defects could be eliminated fairly well by using very long tubes[33], but aerial telescopes introduced other problems as follows.

(2) Long wooden tubes gave rise to defects like warping, shrinking or swelling. Besides, the telescope became very unwieldy to mount, and to operate by means of rods and pulleys. A stable image in the small field of view was a problem so also the alignment of the objective and eye-piece lens.

(3) Until the invention of a ctoss-wire in the eye-piece and also of the micrometer by Gascoinge (1619-1644) already in 1640/41[34] the telescope could not

be employed as an instrument of measurement, say, determination of the angular distance between two heavenly objects. In fact, initially telescopes were mounted on angle-measuring instruments like quadrants, sextant as *telescopic sights*. However, a good deal of controversy then arose about the accuracy achieved. Whether the accuracy measurement was more by telescopic than by open sights became debtable. A very strong supporter of the latter was Hevelius (1611-1687) of Danzig, who corresponded actively with Hook (1635-1703) and between 1676-1679 with Astronomer Royal Flamsteed (1646-1720), both of whom were in favour of telescopic sights,[35] Let us take note of this stage in the development of telescope in the very person of Johann Hevelius of Tychonic school.

In support of open and bare sights fixed on his quadrant of 5 feet radius and some of 6 ft. he argued,[36]

> "I question whether these telescopic Sights, so near the Eye, can discover the smallest Stars much more accurately, than our plain Sights, which are distant from each other Six or Nine feet. For, though by these Telescopic Sights, one may see the object more distinctly; yet because they are so nigh to the Eye, one may err, more than 'tis possible by our plain Sights, that are so far as under."

One should not forget that Hevelius himself constructed initially telescopes of less than 13 feet focus and used them for mapping the lunar surface; that work was published in his *Selenographia* in 1647. Actually later he became a great specialist in making long telescopes of 60, 70 feet focus and finally of 150 ft, which he described in his famous work *Machinae Coelestis pars prior* (Gedani 1673)[37] All the same he rejected stubbornly the use of telescopic sights altogether. It is said that his claim to achieve an accuracy of less then 1 minute of arc for his instruments with open sight was admitted unbelievingly by Halley after his visit to Danzing in 1679.[38] Repsoli had had tried to explain Hevelius' viewpoint by assuming that he was gifted by a remarkably sharp eyesight and was so much accustomed with his techniques of observations, that he could achieve quite extraordinary accuracy of measurement. Further, he used to have fixed stable, non-vacillating instruments of Tychonic type and his metal quadrants and sextants were not less than of 3 ft.[39] Thus even at the close of the 17th century, the telescope as a device for measurement was not completely settled. Allen is right when he says that the seventeenth century ideas were brought to perfection in the following two centuries by time and industrial revolution.[40]

Keeping this historical perspective in mind, can we question Jai Singh (who was primarily schooled in the West-Central Asian and Indian astronomy) for not readily accepting the telescope as a measuring device?

Let us note that Jai Singh was also motivated to build huge masonary instruments at his observatories due to exactly the same afore-mentioned defects in the metal or wooden instruments of West-Central Asian school of astronomy, viz. warping,

bending, swelling etc., and because of the most important problems of mounting and stability. By employing masonary instruments—his wall-quadrant was of 20 ft radius and gnomon with the vertical height of about 90 ft-he tried to increase his accuracy considerably. It is therefore quite plausible to assume that he rejected the use of telescope as a measuring device on *scientific grounds* quite objectively because of the type of the telescopes available to him.[41]

The Planetary System

It may also be pointed out that Jai Singh's reception of European astronomy was not confined to just the use of telescope, but he also accepted the European emphasis on observations. Consequently he matched the observations *(marṣūd)* with theory *(maḥsūb)* in contrast to his predecessors. It was thus found by Jai Singh's astronomers that the orbits of the Sun and Moon were ellipses. But he does not state anywhere that the same was true for other planets. Thereafter Jai Singh dealt in ZMS the geometry of the ellipse in detail.[42] However he stuck to the geo-centric model of the planetary motion despite his elliptical orbits.[43]

It may be asked why Jai Singh did not use heliocentric system when Johan Raptist Hoemann's *Grosser Atlas uber die gazne Welt* (Nurenberg, 1725) was available to him. The date of acquisition of this Atlas is 1730, the year when his delegates returned from Portugal. The Atlas, still extant at Jaipur, contains charts on the planetary system of Copernicus (chart 10) and Tycho Brahe (chart 13); the Egyptian and Riccoli systems are also drawn in the margin of chart 13. Thus the heliocentric and geo-heliocentric systems should have been known to him. And yet he completely ignored it. Has his inability to appreciate or accept the new heliocentric system any parallel in Europe, say in the 16th century? The answer is in affirmative.

It has been shown by Schofield that prior to the establishment of Tychonic system (in 1588) a number of attempts were made in favour of geo-heliocentric systems, viz. by Erasmus Rheinhold (1511-53), Albert Konicerus (died 1614) and Christopher Rothmann (16th c.) On the other hand, no less than any great scholar of his times, the French mathematician Francois Viete (1540-1603) modified Ptolemaic model by replacing "some epicycles and deferents by epi-ellipses and elliptical deferents" [44] As a matter of fact the use of the latter specifically "as a kind of oval" is known to have been invented already by Al-Zarqālī (1029) in 11th century and employed in 15th century Europe by the expert of Arabic-Islam astronomy George Peuerbach (1423-61).[45] In this connection we may also recall the opinion of Dijksterhuis that the "introduction of the helio-centric world picture as such could not lead to greater accuracy of the planetary tables."[46] It is therefore not surprising that "no textbook widely used in Europe in the 16th century expounded Copernicus theory and few even mentioned it."[47]

If in the continent of Copernicus (1473-1543) "in the sixteenth century itself.... the effect of his achievement.... was only slight and it did not begin to assume a

clearer form until about 50 years after his death,"[48] how could one *censure* Jai Singh for not accepting the heliocentric system just by Jesuits' hearing if at all.[49] As in the context of the 16th century Europe, "immediate acceptance of Copernican system is simply an unwarranted expectation by us today",[50] so also should be the case with the reception of Copernican system in the 18th century context of Central West Asian and Indian astronomy.

EUROPEAN ASTRONOMY IN INDIA DURING 17th—19th CENTURIES

With the invention of the telescope in Holland sometime around 1608, its utilization by Galileo in 1610 for astronomical observations and its development later as a measuring device, European astronomy developed in the 17th century quite on practical lines. That is, it was purely positional astronomy, in which both optical telescopes and mechanical clocks (or chronometers) were used as main instruments. The dissemination of that astronomy into India appears to have taken place in three stages:[51]

(i) Astronomical observations of heavenly bodies by individuals, especially by the Jesuit astronomers and cartographers;
(ii) Organized efforts leading to planned systematic astronomical observations; and
(iii) Establishment of astronomical observatories.

In this section we show that apart from individual efforts, the systematic astronomical observations initiated at the close of the 18th century led to the establishment of a number of astronomical observatories in several famous Indian cities: Madras, Calcutta, Lucknow, Trivandrum, and Poona. Excellent astronomical work comparable to that of any 19th century European observatory was done at these Indian observatories.

European Background

During 15th—18th centuries, astronomy was developed in Europe not only as a pure science, but more so on practical lines.[52] The great age of European exploration of the four continents began in about the later half of the 15th century.[53] Portugal and Spain were the first to become maritime powers. We may recall here, for instance, the voyages of Columbus to America in 1492—93 and of Vasco Da Gama to India in 1498. Thus navigation and geography progressed hand in hand. The requirements of that age were land maps, maps of harbours, coasts and islands. Beginning with the use of magnetic compess, the mariners and also cartographers employed astronomical quadrants for the measurement of geographical latitude, followed by sextants, and telescopes in conjunction with chronometers[54] to measure both latitudes and longitudes in the 17/18th centuries. Already in the 16th century, cartography was boosted commercially in almost all European countries. Map production, rather printing by employing copper plates engravings, became then a big business in Europe. The following account may to noted,[55]

> "Queen Elizabeth saw a wave of enthusiasm for discovery sweep over England, rousing sailors, soldiers, merchants, persons, philosophers, poets and politicians to vie with each other in promoting expeditions overseas for the glory of their country and their own fame and profit. The gallants of the *courts were ready to command the expeditions for which the shrewd city merchants found the means......*"

It is also told that the "European market was full of printed charts, sea atlases, globes, wall maps, towns plans, views and above all atlas maps".[56] It is therefore natural that commerce and navigation reinforced each other in the 17/18th century Europe. However for good mapping one required accurate geographical coordinates: the latitude and longitude,[57] which were determined astronomically by the observations of Sun, Moon and satellites of Jupiter. What was required then was in fact, accurate astronomical tables/charts for the motion of Sun and Moon, and star catalogues. That was impossible without the establishment of observatories and their governmental sponsorship;

> "In the seventeenth century astronomy began to be a government affair. Formerly in Tycho's time, princes had often endowed astronomical pursuits, which were personal hobbies of single individuals.
> In the next century, under royal absolutism, astronomy, besides being a personal scientific activity of a class of wealthy enlightened citizens,[58] eager of knowledge, also took the form of state employment. The practical application of astronomy to the needs of navigation and geography induced the rulers to found observatories."[59]

In that socio-political context the observatories at Paris (commissioned in 1667 and at Greenwich (1675) were established under the royal patronage.[60] The character and nature of work at the two observatories were somewhat relatively different. While at Paris, the astronomers were pursuing the science of astronomy, the objective and aim at Greenwich were geared practically to navigation. However this emphasis of work was not followed very rigidly. For instance, Paris Observatory sponsored one expedition to measure meridian arc-length of 1° near equator, and another for precise determination of solar parallax (i.e. Sun-Earth distance) by observing the transit of Venus in 1761 and 1769.[61]

Finally we may mention that further advances, particularly, in the construction of telescopes were realized by refinements in optical techniques which in turn weie implimented by the industrial revolution in the second half of the 18th century England[62] [63] The technical basis and progress in astronomy, geography, cartography and navigation was then assured by the rise of big industry in 19th century Europe, a factor completely missing then in India and playing only now in independent India its pivotal role!

The Jesuit Contributions

The Indian Situation

In the context of the development of cartography and practical astronomy in 16/17th century Europe as briefly outlined above, it is not surprising that the Jesuits who came to India and even went as far as China or Japan were learned men, particularly trained in the art of geography/cartography and therefore practical astronomy.[64] As a matter of fact they were first Europeans to introduce modern Western astronomy into South and South-East Asia, when the Church dropped gradually the initial opposition to post-Copernican telescopic astronomy. Alternatively, it was also then hoped that the "European art and sciences (like mathematics, mechanics, astronomy, painting, music, medicine) were the only support which could prop the very weak and slow propagation of Christianity, besides winning the monarch's favour and goodwill for Christians, particularly his conviction for Christianity."[65]

After the colonization of Goa in 1510, its consolidation in the following decades and the establishment of the Jesuit order in 1534 by Pope, John III of Portugal requested the Pope to establish a Jesuit mission in India. A group of Jesuits headed by St. Franci's Xavier set out in 1541 to establish a mission in Goa, which was then extended to Travancore Cochin by 1533.[66] In any case a multitude of missions by Jesuits and by other Catholic orders and countries (like French, Dutch, German and quite late in 1833 by English) were founded throughout the length and breadth of India.[67] That those Jesuits involved themselves in many academic and/or missionary activities is not our concern here.[68] We are here interested only in their astronomical observations and therefore in the sequal we deal briefly with the most important Jesuit cartographers cum astronomers who became quite popular at the courts of Mughal emperors and local rulers.

As early as 1568, the fame of the Jesuits' scholarship reached the court of Emperor Akbar (1542-1605) who requested the viceroy at Goa to send missionaries to his court. Father Anthony Monserrate (1536-1600) was one of the members of the first Jesuit mission to the court of the Mughal Emperor.[69] The Jesuit determined geographical coordinates of about hundred positions on his way from Fatehpursikri to Kabul, while accompanying Akbar in 1580/81. It is not widely known that Monserrate was the first foreigner to compile a map of India c. 1590. It was a small map but "partly based on measured routes and astronomical observations.... though it is seriously out in longitude".[70]

Father Jean-Venant Bouchet (1655-1732) went to Pondicherry in 1689 where he is reported to have carried out astronomical observations for the sake of surveying the peninsula, particularly determining the geographical positions in 1719 along the Madras coasts. His map of the interior was "the first map of any merit", dated 1722.[71] The cartographical work of Father Bouchet was utilized by D'Anville (1697-1782) in his "*Carte de Cote de Coromandel,* (published in Paris 1753, in London 1754).[72]

Father J. Richaud (1633-1693) was already a well-known astronomer when as a member of the French embassy he left for Siam in 1687 "as mathematician of France". The title was bestowed upon him by Louis XIV. From Siam he came along

with Bouchet to Pondicherry in 1689, where he set up his 12-ft telescope. His most significant observations were; (1) the comet of December, 1689; (2) binary nature of *alpha-Centauri* and alpha-Cruis; (3) exact prediction of the occurence of lunar eclipse of April 4, 1689, (4) latitude and longitude of Pondicherry and that of Mylapore (San Thome); (5) zodiacal lights at Pondicherry in 1690; and (6) the Megallanic Clouds and two dark clouds towards Coalsack. Besides carrying on astronomical observations he also taught astronomy at the Jesuit school, then started at Mylapore.[73]

The most well-known astronomer-cartographer was the French Jesuit Claude Stanisla Boudier (1687-1757 at Chandarnagore) who became so much reputed as an astronomer that Maharaja Jai Singh II invited him in 1734 to take observations at Jaipur. During the course of his journey, Boudier determined both latitudes and longitudes of 63 Indian cities in 1734, and also meridional altitudes of a few stars.[74] We mention below some of Boudier's observations to determine the longitude of various places;[75] (1) observation of the first satellite of Jupiter, on April 2, 1734 at Fatahpur; again at Jaipur on August 15, 1734; (2) solar eclipse of May 3, 1734, at Delhi; and (3) lunar eclipse of Dec. 1, 1732.

Boudier was in constant touch with Father Gaubil at Peking, whose simultaneous observations he utilized in his calculation for difference of longitudes; for this purpos he used also Cassini's observations at Paris. He also possessed La Hire's table (edition of 1702). It may also be mentioned that Boudier used a watch and a 17 ft long telescope,[76] and an aperture gnomon.[77]

Besides the meridional altitudes of a few stars, Boudier carried out observations/calculations for the length of the year, the diameter of the sun, the obliquity of the ecliptic and its variation.[78] However, Father Gaubil considered value of the diameter of the Sun as over estimated. In fact Gaubil critized Boudier as follows :

> "It is several years since I received any thing from Father Boudier. He has, undoubtedly, sent every thing to Paris. Hower, I have a good part of what he did, till 1738 and 1739; and I find that he is much mistaken with respect to the diameter of the Sun and the obliquity of the ecliptic. I do not know whether the right ascensions of the stars are very exact. He had not then any knowledge of the oberration of the stars.[79]

Nevertheless he appreciated Boudier's determination of geographical coordinates: "His (Boudier) journey from Bengal to Agra, Delhi etc. along with observations inform us at last the true position of Delhi and Agra."[80] Both D'anville and Tieffenthaler had utilized Boudier's values of latitude and longitude extensively.[81] According to D'anville Boudier was "Très habile dans l' Astronomie, qu'il a cultivée par inclination."[82]

For the sake of completeness we may mention here the Portuguese Superior of Jesuit Father Emmanuel de Figueredo (1690?—1753?) who came into contact with Raja Jai Singh II about 1729 and reported to him the "grand progress in astronomy achieved in Portugal."[83] As a result, Figueredo went to Portuguese king Don Juad V, as head of an embassy of Jai Singh, in 1730 and returned to India with a number

of European works, especially Phillipe de La Hire's astronomical tables (edition 1702).[84]

In passing we may also mention the Portuguese Father Xavier de Silva,[85] the German Father Cabelsberger[86] (1704-1741, died at Jaipur) and Strobel[87] (1703- who assisted Maharaja Jai Singh in his mathematical astronomical activities. About father Jean Calmette, (1725-1740 in India) with whom Jai Singh corresponded to on his doubts regarding the underlying geometrical model of the astronomical tables of La Hire, it is known that his value of obliquity was different from that of La Hire and that he was primarily engaged in determining geographical positions for a map of South India.[88]

Finally we shall like to conclude this section by giving a brief account of Father Joseph Tieffenthaler (1710-1785) who came to India in 1740, and died at Lucknow.[89] Tieffenthaler became famous especially for his *Historical and Geographical Account of Hindustan,* published both in German and French (see the bibliography).[90] In fact, as an excellent cartographer/geographer, he was engaged in several astronomical observations with which we are particularly concerned here They are:[91]

(1) Meridian altitude of the Sun at various Indian cities of India for the determination of latitudes.

(2) Solar and lunar eclipses,

(3) Jupiter's occultation by Moon on Feb. 2, 1744 at Surat, and also immersion and emersion of its satellites.

(4) Transit of Mercury on Nov. 4, 1743 at 2 P.M. in Goa. He described the planet a glowing coal across the solar disc" and lamented his inability to observe the beginning and the end of the phenomenon for want of astronomical instruments, and making his observation useless for astronomy.[92] In fact, Tieffenthaler mention in his geographical work at various places the astronomical instruments at his disposal, namely, astronomical quadrant of brass and astrolabe.[93] Most probably he could also use the instruments at Jai Singh's observatories at Delhi, Jaipur, Ujjain, Benaras and Mathura, on which he reported fairly well.[94]

In comparison with his Jesuit predecessors, Tieffenthaler seems to us an excellent scholar, quite familiar with the post-renaissance European astronomy as well as oriental astronomy. This is apparent from his various references to Latin works (more precisely Latin translations of Arabic works) and from his allusion to the original work of 'Abd Al-Raḥmān Sufī (903-983), the astronomical tables of Naṣīruddīn Al-Ṭusī (1201-1274) and of Ulugh Beg (1394-1449)[95]. Besides he wrote in Latin a monograph on Indian astronomy and astrology.[96]

A Parallel Situation in China

We would like to digress here to a parallel situation in China regarding Jesuit contribution in order to draw certain conclusions for the Indian situation. A number of prominent mathematician-astronomers went to China during 16—18th centuries and took part in the promotion of mathematical astronomy, in particular. The most important who wrote in Chinese were : Metteo Ricci (in China 1583-1610), Joh. Schreck[97] (arrived in 1618) Adam Schall Von Bell,[98] F. Verbiest[99], I. Kogl[100] and A. Von Hallerstein.[101] Their importance can be gauged from their academic back-

ground and/or contact with the European scholars of 17th century. Ricci had been a student of and became later a friend of Christopher Clavius;[102] Schreck (*alias* Terrentius) was in active correspondence with Galileo and Kepler. In fact he knew both of them personally. Kepler sent him in 1627 even Rudolphine Tables. He even brought a telescope with him and presented it to the Chinese emperor in 1634.[103] On the other hand, Schall was inspired in his youth by telescopic discoveries of Galileo.[204] And Kogler was quite well familiar with the observational work of Flamsteed and Cassini.[105] In a way therefore it is not surprising that the following remarkable works on calendarical/astronomical sciences were written by those knowledgable scholars *in Chinese*:[106]

(i) *Ricci Corpus,* part II comprises two works on astronomical and calendar calculation/theory and five works on astronomical techniques, written during (1607-1632).[107]

(ii) *Brief Description of the Measurment of Heavens* (1628) in which, without naming Galileo, Schreck mentioned the Sunspots and the phases of Venus; "it being a satellite of the Sun".[108]

(iii) *The Far-seeing Optik Glass* (1626), a treatise on telescope by Adam Schall, in which again Galileo's name was not mentioned. The same was the case in Diaz's book *Explicatio Sphaera* (1615) where telescope and Galileo's discoveries were given for the first time.[109] As a matter of fact only in 1640 with the publication of Schall's *History of Western Astronomy,* the names of Galileo, Tycho Brahe, Copernicus and Kepler appeared in Chinese.[110] However, Schall in his *Encyclopaedia on Astronomical and Calendric Sciences* follows basically Tychonic system and "no direct discussion of Copernicus' heliocentric theory is given in his encyclopaedia."[111]

(iv) Lastly we may also recall the afore-mentioned[112]: [88]*Sequel to the Compendium of Observational and Computational Astronomy* (1742), by Ignatius Kogler and his assistant Andrew Pereira, in which though "improved constants and tables based on the observations of Cassini and Flamsteed" were incorporated along with Keplerian ellipses, yet the *model of the planetary motion was actually Tychonic.*"[113]

Let us conclude this digression in the words of the famous historian of Chinese Science N. Sivin: Nontheless,[114] sixteen years after the death of Newton thirteen years after the announcement of Bradley's discovery of stellar aberration, heliocentrism was still anathema in China. It was Kepler's old master Tycho Brahe furnished the scenery. The Earth was static,......while the Sun and Moon rode about the Earth on ellipses, the planets were still making their rounds of the Sun on the cranky epicycles of Tycho,[115]

We have discussed at length the Jesuits astronomical work in order that one could differenciate the Chinese vis-a-vis Indian situation during the 17—18th centuries.[116] First not a single treatise or monograph on Western science in Persian or Sanskrit written by Jesuit scholars working in India is known to-date, excepting a stray reference to the Persian translation of Gassendi's and Descartes philosophies.[117] Second, obviously the early Jesuits in China as well as in India, like members of other orders: Dominicans, Franciscans etc., wished to preach primarily the Gospel[118] and their strategy was to convert the elite (Emperors, Rajas and high officials) so as

to achieve wholesale conversion. However in China the Jesuits "desired to convince the Chinese of the superiority of Western religion by demonstrating the superiority of Western Science in their day and age"[119] for example, correct prediction of eclipses etc. As a result a huge production of literature on modern science or astronomy in Chinese language was achieved. On the other hand, that kind of motivation was not at all required by the Jesuits in India, since for instance Emperor Akbar (1556-1605) invited thrice for disputations Christian missions from Goa to his court, namely in 1580, 1591 and 1595; Jahangir (1605-27) is also said to have protected the missions.[120] Third, barring a couple of them like Boudier and Tieffenthaler, the Jesuits in India were mostly no good astronomers or scientists; they were also not in correspondence with the best European astronomers in contrast to those in China as mentioned above.

Finally we may note that despite all that afore-mentioned astronomical literature in Chinese, the introduction of Copernicus, heliocentric system *was withhold* by the Jesuits till the removal of his work *De Revolutionibus* (already published in 1543) from the list of banned books by the Catholic Church in 1757. Only in 1760 the famous Jesuit astronomer M. Benoist (1715-1774) could venture to explain the Copernicus' world system in his work.[121] However, in India the year 1757 was a crucial one, when the battle of Plassey took place and by 1765 the East India Company (EICo) had gained virtual control of the whole of Bengal. The acceleration of the decline of Mughal empire thereafter generated a political chaos in which the transfer of European science could not serve the Jesuits' main purpose of proselytization in anyway. From then onwards all political and also scientific activity in India passed into the hands of EICo; we discuss the latter in the following sections. In passing we may add that in the last decade of 18th and throughout 19th century, despite the political turmoil and instability in the country, several Indians attempted to contribute themselves to the transmission of European astronomy.[122]

The Beginning of Organized Efforts

With the commencement of the age of world-wide exploration in the 15th century and its further growth during 16—17 centuries, an era of European armed colonization began in the Afro-Asian countries, in order that their natural resources could be exploited by European powers for commerce, trade and capital accumulation in particular. As a result the Indian sub-continent was also teaming with colonial powers: Portuguese, Dutch, French and English. The East India Company (EICo), founded in 1599 for the promotion of trade between England and the East, could establish its first factory and warehouse at Surat (on the West Coast of India) in 1608, and later more factories at Madras, Bombay and Calcutta. The strategy of EICo, to promote trade not only with diplomacy but also by wars and finally by full control of the territory, bore excellent "fruits". In the unstable socio-political atmosphere during 17—18th centuries, when the Mughal power declined and the then Indian empire started to disintegrate, a clever exploitation of author by EICo gave rise to a rapid ascendency of the Company to paramountcy. It has already been mentioned that in 1757 the battle of Plassey had been quite decisive. By 1765 the whole of Bengal (including Bihar) was under the virtual control of EICo. In fact the Company was also successful in driving out from South India the French (after three consecutive Carnatic Wars during 1746-1763), gaining

control of the Madras Presidency, confining the French influence to Pondiehcrry only and in bringing under its control also Nawabs of Mysore and Nizams of Hyderabad in the last decade of the 18th century. Thus at the beginning of the 19th century EICo was to be reckoned as the imperial authority in nearly three-fourth of the sub-continent.[133]

For the sake of gaining knowledge of the Indian Sub-Continent and its natural resources, establishing an efficient communication network and particularly for revenue purpose, EICo started its geographical surveys quite systematically, already in the sixties of the 18th century. It may be recalled that the earlier map of India by D'Anville & J. Rennel (1742-1830)[124] were based largely on geographical tables of Ptolomy (fl. 150 A.D.), Naṣīruddīn Al-Ṭusī (13th c.), Ulugh Beg (15th c.) and of the Indian scholar Abul Faḍl as given in his *Ā'in-i Akbari* (16th c.).[125] But since these tables were not accurate enough and by no means were based on systematic astronomical observations, the cartography in India was especially promoted by EICo, with the aid of its own surveyors. Mention may be made here of the works of the following personalities who emphasized the astronomical observations in particular.

Rev. W. Smith (c. 1775 in Bengal) carried out astronomical observations "for the sake of amusement and to help the cause of geography."[126] Employing a Dolland telescope of 3½ ft. with a triple objective furnished with micrometer and also a quadrant, Smith determined the longitude of places by standard methods; eclipse of Jovian satellite, occultation of stars by Moon and latitude from meridional altitude of stars. Smith left "55 large folios" of astronomical observations. The accuracy of his geographical work was appreciated even by Rennel.[127]

Smith sold his instruments to J. D. Pearse (1741-1780), a commander of artillary and such a keen regular observer of astronomical/meteorological phenomena that he took observations during marches of Mysore War.[128] Besides using Smith's instruments, he employed also a 18″ quadrant and a sextant of 6″ radius, made by Ramsden. Many of his cartographic and astronomical observations were published in *Asiatic Researches* and a good number of them (carried out during 1778-1781) on board the ship "Bengal" are said to be still extant in the Library of the British Museum. Pearse was a personal friend of Governer General Warren Hastings, was in correspondence with Astronomer Royal N. Maskelyne and Sir Robert Barker and supported whole-heartedly Burrow's astronomical survey plan of 1787.[129]

We have already described briefly the European age of world exploration which boosted evidently the map-making business during 17-18th century Europe. The science of cartography is primarily based on the determination of geographical coordinates—the latitude and longitude. However, the problem of determining the longitude at high seas for accurate navigation took an unusually long time to solve, i.e. till the chronometer method was invented.[130] The importance, rather urgency of that problem can be appreciated by the fact that "a petition by sea-captains and London merchants to provide a public reward for the discovery of (a good method to determine) longitude at sea" was presented to the British Government. To that end a bill for the following rewards was passed in 1714 by the British Parliament:[131]

(i) £ 10 000 for a method with an accuracy of 1°, corresponding to 60 nautical miles;

(ii) £ 15 000, for an accuracy of (2/3) degree, corresponding to 40 nautical miles;

(iii) £ 20 000 for an accuracy of $\frac{1}{2}°$, corresponding to 30 nautical miles.

To assess the various individual claims, a Board of Longitude consisting of 22 members was also constituted. For instance, one of the members of that Board was E. Halley (1656-1742), famous for his comet of 76 years' period. The problem of determination of longitude was in fact so important[132] that even the observations of rare phenomena like transits of Mercury and Venus were suggested, already in 1691 by no less than Halley himself.[133] In particular, the transits of Venus of June 6, 1761 and June 3, 1769 were proposed for the world-wide observations, because of their long duration of about seven hours.[134]

The Royal Society at London (founded in 1662) was interested from its earlier years in accurate navigation. On the request of the Society the Directors of the EICo decided to organize in a planned way the observations of the two transits.[135] The directors even declared in 1768 that such observations "will afford the only means of ascertaining some principle and hitherto unknown elements in astronomy and of improving both geography and navigation......"[136] To that end, the following instruments were imported officially into India: (i) a reflecting telescope of 2 ft. focus, (ii) a pendulumn clock, and (iii) an astronomical quadrant of 1 ft. radius.[137]

A number of EICo's engineers succeeded in observing the transits of Venus: From the observation of B. Plaisted (d. 1767) at Chittagong, the Astronomer Royal deduced the longitude of Islamabad as 91° 45'; Rev. W. Hirst (d. 1770) observed it at Madras in 1761; L. F. De Gloss (in India 1753-1774) at Dinapore, J. Call (1732-1801) didn't succeed because of cloudy weather. The same bad luck was met by the Frenchman Guillaume Le Gentil De La Galaisiere (1725-1792), who was sent by the Academie Royal des Science (Paris) for observing the transits. In 1761, he arrived in India late, after the expiry of the phenomenon. For the transit of 1769, EICo put at his disposal the best telescope of Madras. But for the clouds which obscured the Sun during the occurrence of the transit he could not realize his ambition for which he waited in the Indian Ocean for 8 years. However, between 1761-1771 Le Gentil surveyed the environ of Pondicherry for latitude and longitude by observing eclipses of the Moon and satellites of Jupiter, also lunar hour-angle. He compiled a table of refraction, determined the length of second's pendulum and carried out magnetic measurements in the South Indian Ocean.[138]

Finally we must mention the notable astronomer R. Burrow (1747-1792) who was the first to emphasize the extreme importance of founding the Indian geographical surveys on *regular* astronomical observations.[139] As the most talented astronomer, at one time assistant of Astronomer Royal, N. Maskeylyne and astronomy teacher for engineers at Fort William (Calcutta), Burrow took part in many geographical explorations. "Notable", as he was, "for his effort to break away from the common place", he criticized severely the method of surveying in India by EICo:[140] "Geography is so little benefitted by such maps (i.e. the English ones) that they are a nuisance rather than advantage, and there is no other proper method of correcting such surveys but by determining the positions of some of the most material points by astronomical observations". Thus Burrow recommended a regular astronomical survey, also some physical observations,[141] emphasized "on precise

determination of actual and relative positions"[142] of places, and even *an astronomical observatory* for India in order "to make corresponding observations with the aid of a 4 ft. reflecting telescope, a theodolite made by Ramsden, a sextant of 6" radius made by Troughton and an Arnold's chronometer, Burrow carried out extensive astronomical observations particularly during 1790-91.[143] After his death his observation on reduction led to the following values for one degree of longitude (at 23° 28' N) and latitude as 55989 fathoms and 60457 fathoms respectively.[144] It has been assessed that his observations "were of a far higher standard than are hitherto taken in India and for the next 30 years (were) accepted as the best available....[145] In favour of his genius for astronomy, one may cite the information that he mastered Sanskrit for translations of old manuscripts, wrote astronomical notes in Galdwin's translation of Abul Faḍl's *Ā'īn-i Akbari,* and recommended the use of large quadrant at Banaras Observatory.[146]

We may conclude this section by adding that his efforts led to the regular astronomical control of geographical surveying, thus indirectly supporting modern astronomical activities on Indian soil.[147] As an example we may quote the sailor-surveyor Michael Topping (1746-1796) who observed with a Dolland's telescope in 1785 eclipses of satellites of Jupiter in order to determine longitudes in the Maldive Island, and utilized also his 55 meridional observations of fixed stars to ascertain with exactness the latitude of the Company's House at Coringa Bay.[148] In the following section we deal briefly with Topping who in fact was the *driving force fer getting the first modern Western Observatory established in India* at Madras in 1792. He took the Board of Directors of EICo at their word and pleaded: "Astronomy has ever been acknowledged as the Parent and Nurse of Navigation and it is doubtless from considerations of this nature that the Hon'ble Court have come to the resolution of thus affording their support to a Science to which they are indebted for a rich and extensive empire."[149]

THE ESTABLISHMENT OF OBSERVATORIES

Since the development of astronomical knowledge is closely related with the establishment of observatories we go over to their foundation by EICo and also by Indian monarchs. In particular we relate their origin, growth and astronomical work performed there by various astronomers/directors whose brief biographical sketch and conditions of work then are also narrated. Finally we list the astronomical instrumentation employed at those observatories from time to time, which in turn reflects directly the standard of astronomical activity. Wherever possible a glimpse of the scientific outlook of the astronomers working then in India is also given.

According to our present knowledge, the following modern observatories were established in Indian during 18-19th centuries.[150]

1. Madras Observatory (1792);
2. Calcutta Observatory (1825);
3. Royal Observatory at Lucknow (1835);
4. Raja of Travancore Observatory at Trivandrum (1837);
5. Poona Observatory (1842);
6. St. Xavier's College Observatory at Calcutta (1875);
7. Maharaja Takhtasingji Observatory at Poona (1882);

8. Hennessy and Haig Observatories at Dehra Dun (1884, 1886);
9. Presidency College Observatory at Calcutta (1900).

It should be mentioned at the outset that all other observatories except the Madras Observatory were either abolished or later stopped astronomical work altogether. In the last section of this contribution we dwell upon briefly the reasons for that state of affairs.

The Old Madras Observatory

The history of this famous observatory established by the East India Company has been treated in a number of works, [151] [152] [153] and therefore we recall in the following its origin and establishment only briefly.

Michael Topping (1747-1796).

The only sailor-astronomer of all the surveyors stationed at Madras, Topping came to India in 1785, when he engaged himself in the determination of longitudes in the Maldive islands and in Ceylon.[154] In 1787 he was engaged in coastal surveys north of Masulipatam[155] and "southward to Cape Comorin......(to) ascertain the position of the principal places in Carnatic."[156] He utilized for that purpose "an excellent instrument on the Hadlean principle" by Stancliffe, an artificial horizon and telescope by Dolland, also on Arnold's chronometer. He employed the satellites of Jupiter for longitude determination, for latitude used his meridional observations of fixed stars.[157] By 1788 he completed his chart of the Coringa Bay. [158]

In 1789 Topping suggested to the Madras Government to acquire the private astronomical observatory of William Petrie[159] who, while departing for England, then, "offered his instruments as a gift to the Government". Topping argued:" The Company had, from time to time, sent many valuable Astronomical Instruments to Madras, most of which for want of a proper deposit and of proper persons to render them serviceable had been scattered abroad in different parts of the country."[160] He then listed the following instruments: (i) 2 astronomical quadrants, one by Bird, (ii) 2 acromatic telescopes with a triple object glass by Dolland, (ii) 2 astronomical clocks with compound pendulum, (iv) time-keepers by Shelton, and (v) transit instrument presented by Petrie.

To start with, Topping thus floated the idea of a *depository* erected for Petrie and Company's instruments, so as to protect the instruments" from the hazard of injury and usage, if not total demolition....".[161] He also praised the EICo for his efforts to support scientific work, as quoted in the preceding section. In 1790, the Directors of EICo agreed that "the Establishment of an Observatory at Madras would be very great advantage to science,"[162] and after two years during the Governorship of Sir Charles Dakeley, he was appointed the first Director of the Madras Observatory, with John Goldincham as his assistant,[163] and later by an Indian.[164]

Already in 1791 the house of one Edward Garrow was used by Topping for his instrument and office. By 1792, the observatory was erected.[165] Topping describes in detail in his report the building plan of the observatory. We confine here however to the remark that granite pillars or foundation-towers were constructed to keep the instruments free of vibrations, one each for mural arch or circular instruments for taking meridian altitude, for the instrument for taking equal altitude observations

and for the transit instrument by Stancliffe. The remains of these pillars are still extant at Madras.[166]

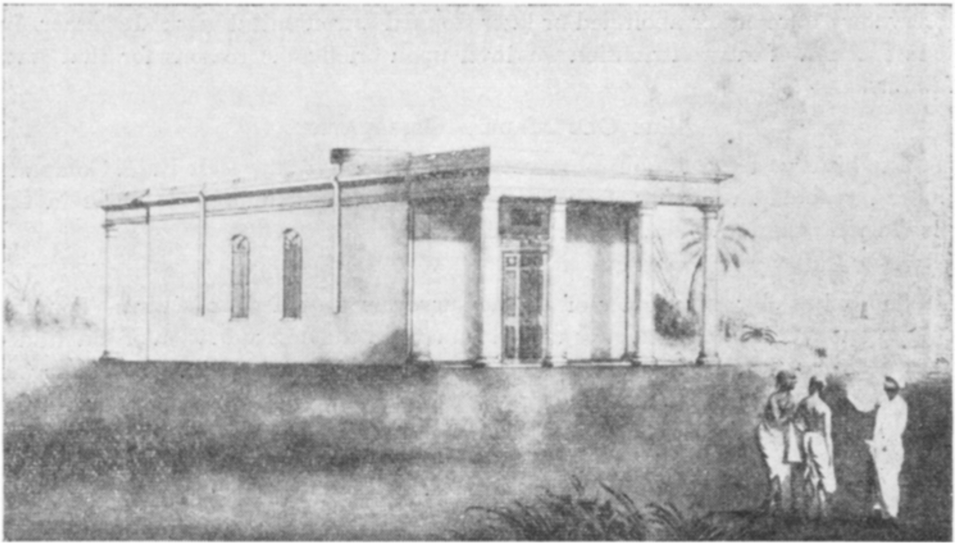


Fig. 12.1. Madras Observatory

As a person of very considerable mathematical and geographical knowledge[167] he knew very well that," every correct observation made at Madras that has a corresponding one with which to compare it, taken under any meridian, determines at once the relative longitudes of the two places". In fact Topping was convinced that the "astronomical observations (were)....the only sure and practical method of finding the relative position of distant trans-marine situations" and he hoped for "the chart of these Eastern Seas in a more correct state than those even of Europe....or at least a regular system established for the perfection of Indian Geography."[168]

John Goldingham (*d.* 1849)

Topping was succeeded by the Dane John Goldingham who had assisted W. Petrie at his private observatory before becoming an assistant of Topping. He held the post of Government astronomer from 1796 to 1830. During his tenure he equipped the observatory with a circular instrument of 15″ diameter made by Troughton and also with a vertical and horizontal circle.[169] Moreover, one portable transit by Ramsden, two more astronomical clocks and Dolland's telescopes were acquired.[170]

Goldingham's astronomical observations were published in four volumes. His work comprised mainly the observations of transits and zenith distances of heavenly bodies, solar and lunar eclipses, satellites of Jupiter and lunar occultations of fixed stars.[171] He also performed valuable pendulum measurements near the equator and at Madras, observations of the velocity of sound, and kept a meteorological register since 1796.[172]

To appreciate Goldingham's scientific outlook we quote from one of his communications to the first Surveyor General of India, Golin Mackenzie (1754-1821):

> "....A Public observatory..is an establishment for observing the heavenly bodies to ascertain their exact positions and motions with a view to the improvement of the tables and geography and navigation..Most enlightened princes have been proud to have such establishments in their dominions as, independent of their utility to science and navigation, none lead to discoveries so sublime regarding the widsom, power and goodness of the Deity; they also become a sort of focus for real science to emanate from."[173]

Goldingham's notable contribution to geography is said to be his determination of the longitude of his Observatory as 80° 18′ 54″. Some of his researches were published in *Asiatic Researches.* It may also be mentioned that a number of Indians assisted him in his daily observational programme, namely transit of Sun and of a number of stars in order to regulate the astronomical clock.[174]

Thomas Glanville Taylor (1804-1848)

Taylor who succeeded Goldingham was recommended in 1830 by none other than the Astronomer Royal John Pond. Taylor had worked as incharge of night transit observations at the Royal Observatory since 1822.[175] On his joining the duty at Madras he made it his first task to put up new powerful instruments: a 5 feet transit, a mural circle of 4 feet in diameter and a 5 feet equatorial by Dolland.

The greatest work which Taylor turned out during his 18 years cf service as Government astronomer was the compilation of his fixed star catalogue, which was finally published in 1844 as the *Madras General Catalogue of* 11015 *Stars.*[176] The significance of his work in general and especially of the afore-mentioned catalogue can be appreciated by the report of the Royal Astronomical Society in which it was stated:

> "In the execution of....(the Society's catalogue of stars)....considerable assistance has been afforded by the....catalogues published by Mr. Thomas Glanville Taylor at Madras. The second of these catalogues contains nearly all the stars in the Society's catalogue visible in that latitude and the last two exhaust nearly the whole of Piazzi's celebrated catalogue....The establishment of this observatory is highly honourable to the East India Company and the fruits which it has produced reflect great credit on the zeal, assiduity of Mr. Taylor, the active superintendent".[177]

Even after ten years of its publication Sir George Airy characterized Taylor catalogue as "the greatest catalogue of modern times". And according to Madler, Taylor's observations were "comparable in value to those of Dr. James Bradley and as the first satisfactory accuracy made within the tropics."[178] The highest recognition of his work was his election as a Fellow of the Royal Society in 1842; he was also a Fellow of the Royal Astronomical Society. Besides his stellar work, Taylor also observed Halley's comet of 1836 and that of Wilmot's of 1845. He is said to have accumulated extensive meteorological and magnetic data at Madras.[179]

William Stephen Jacob (1813-1862)

In Dec. 1848 W.S. Jacob was appointed as director of the observatory. To the already existing instruments at Madras he added a 6.3″ aperture equatorial constructed by Lerebour in 1850 and a new meridional circle by Simms in 1856.[180]

Jacob supplemented Taylor's star-catalogue by observing 1440 stars, on the basis of which he corrected the value of the proper motion of a group of stars. Already a well-known expert of double stars of his time[181], he continued their observation at Madras and collected data for 250 double stars. He calculated especially the orbit of *alpha-centauri*.

His planetary work consisted of the observation of the then newly found planet Neptune, estimation of elements for the satellites of Saturn and a corrected value for the mass of Jupiter. He even found in 1852 the transparency of Saturn's ring.[182]

James Francis Tennant (1829-1915)

In April 1858 Captain Jacob left for England due to his illness and gave the charge of the observatory temporarily to Major Worster of Madras,[183] who on Oct. 13 1859 relinquished it to Major J. F. Tennant.[184] However, Tennant joined also as a temporary director for the short period of one year only. On resuming charge he immediately consulted the Astronomer Royal Sir George Airy. In a letter dated Oct. 23, 1859 he discussed in detail with Airy constructional improvements in astronomical instruments: transit, equatorial etc., also their stability with the aid of granite pillars, mentioned his proposal of a revolving dome and erection of time-ball "for correcting all of our clocks and chronometers" by transmitting the signal telegraphically. He informed Airy also about a Newtonian reflector of 18½ ft. focal length being then "retrieved by Major Worster at his laisure". Finally he lamented on his receiving irregularly the *Monthly Notices* and *Astronomischen Nachrichten* and pleaded for early transmission of information.[185] Further, after writing a report on Madras observatory, dated June 14, 1860, he resigned his job as Government Astronomer[186] due to financial reasons.[187]

Though Tennant was not connected with the Madras observatory further, yet we would like to describe briefly his astronomical work in India at large, since his work was recognized by his election as Fellow of the Royal Society in 1869, and to Presidentship of Royal Astronomical Society in 1890-1891.[188] His major contribution was actually in the observation of total solar eclipses of Aug. 17-18, 1868 at Guntoor and Sept. 11-12, 1871 at Dodabetta (Nilgari Hills), and also of the transit of Venus in 1874 at Roorkee, employing then the newly discovered technique of photography.[189] From the point of view of the history of astronomy he was the first to ask questions about the physical nature of solar prominences already in 1867, and to report his spectroscopic observations of the coronal continuous spectrum, and of a bright line from the prominence. After supervising the observations of solar eclipse of 1871, he could compile clearly the information about the constitution of the Sun.[190]

Finally, it may also be mentioned that as a sequel to his observations of the transit of Venus, he proposed a solar observatory for Simla, "especially for observations with the spectroscope and by photography and also for the observation of Jupiter's satellites". His proposal, though rejected, "led to the daily photography of the Sun at Dehra Dun".[191]

Norman Robert Pogson (1829-1891)

Early in 1861 Pogson was appointed Director of the observatory on the recommendation of J. Herschel and C. Piazzi Smyth. He held the directorship for 30 years! To the equipment of the observatory he added especially two new instruments: (i) a transit circle of 42 inches in diameter which was read by six miroscopes

and a telescope of five inches aperture, constructed by Troughton and Simms, (ii) an equatorial with an 8″ object glass.[192]

Before joining Madras, Pogson had worked at a few British observatories,[193] where he soon became known as a first class observer of variable stars and especially of minor planets. He discovered four of them during 1854-1857,[194] and with seven years of joining Madras he discovered five more planets: *Asia* on April 17, 1861; *Freia* on Feb. 2, 1864; *Sappho* on May 3, 1864; *Sylvia* on May 16, 1866 and *Camilla* on Nov. 17, 1868.[195] During this time he also discovered seven more variable stars and another one in 1877; in fact, he continued at Madras his compilation of a *Variable Star Atlas* which he had started at Radcliffe Observatory (Oxford) in 1852.[196] This work was done with the help of his Indian head-assistant C. Ragoonathchary.[197]

Using the equatorial and meridian circle, in the use of which he was supposed to be one of the topmost experts of his time, he prepared a star catalogue based on 51101 observations, carried out between 1862 and 1887.[198] This catalogue included a number of southern stars between 110° and 150° of North Polar distance which were unknown up to that time.[199]

In Dec. 1872 he claimed to have detected the comet Biela, and during 1862-1873 he took five series of opposition observations of the planet Mars in order to investigate the constant of solar parallax.[200] Besides, he was the first to observe the bright line spectrum of the corona at the time of the total solar eclipse on Aug. 18 1868, which he watched at Masulipatam.

It is said that Pogson had an exhaustive knowledge of the astronomy of his time and as an observer only one or two of his contemporaries could equal him. There is no doubt that his 44 years of astronomical activity proved, in the words of John Herschel, his "conspicuous zeal, devotion to and great success in the science of astronomy."[201] In the history of astronomy he is knowne ven today ast he originator of the so-called 'Pogson's scale' for photometric work. It is the logarithmic scale for the light ratio of stellar magnitudes. Further recognition came to him with his election to Royal Astronomical Society and with is nomination in 1878 as a Companion of the Indian Empire.[202]

C. Ragoonathchari (?—1880)

The first Indian astronomer of the last century who contributed significantly to the Indian astronomy was Chintamanay Ragoonathchary. He was head-assistant at the Madras observatory where he served for 35 years under various directors.

He was a skilled observer, excellent at calculations and possessed a capacity to work very hard, owing to which he could claim to share 38000 observations in the *Madras Catalogue of Stars*. His first paper was submitted to the Royal Astronomical Society as early as 1859 on "The Determination of Personal Equation by Observations of the Projected Image of the Sun". He was the first and only Indian in the last century who discovered two new variable stars: *R. Reticuli* in 1867 and *V. Cephei* in 1878. He also participated in the observations of the total solar eclipses of 1868 and 1871. In January 1872 he was elected a Fellow of the Royal Astronomical Society.[203]

C. Michie Smith

After Pogson's death Michie Smith took charge of the Madras observatory as director up to 1899.[204] Besides completing and publishing the work of Pogson, Michie

Smith tried hard to start "the new Astronomy" in India. In his annual report of 1892 he thus presented his case.[205]

> "During the 33 years which have elapsed since the instruments now in use in the observatory were ordered, astronomy has advanced so rapidly along certain lines that the instrumental equipment is again found very defective.....for the "new astronomy"—photography and spectroscopy—there is practically no provision".

The same opinion was also expressed four years later by John Eliot, Meteorological Reporter of the Govt. of India.[206]

By then, as a matter of fact, even the Government of India had "fully recognized the desirability of India cooperating in the important class of observations comprised under the subject of 'Solar Physics' and (had)..sanctioned the erection of a suitable observatory at Kodaikanal"[207] [208] So the foundation of a solar observatory was laid at Kodaikanal in 1895 and its construction was carried out under the supervision of Michie Smith, who acted then as director of both the observatories. By April 1899 the astronomical work at the Madras observatory was confined to mainly meridian observations for time service and some weather forecasting.[209] By the end of 1900 Kodaikanal observatory was completed and started functioning. The programme of work was chalked out by Michie Smith and it was approved by the Observatories Committee of the Royal Society. From then on real organized astrophysics began in India, i.e. at the Kodaikanal Astrophysical Observatory.[210] But its description is beyond the scope of the present article.[211]

To bring this section to an end and to sum up the importance of the Madras Observatory in the last century we would like to quote from the *Memoirs* of Merkham, who wrote in 1878:[212]

> "The Madras Observatory is now the sole permanent point for astronomical work in India and the only successor of the famous establishments founded by Jai Singh....It has produced results which entitle it to take rank with the observatories of Europe".

Unfortunately within less than 100 years this observatory and the men who worked there have been completely forgotten: In a standard reference work like *Encyclopaedia Britannica* (1966), whereas Jai Singh's observatory at Jaipur is mentioned,[213] there is hardly a single sentence on the history of Madras Observatory and its contribution to the astronomy of the last century.[214]

In conclusion it may be admitted that though the above-mentioned account appears to be quite detailed yet the author is well aware of its shortcoming. A good number of original records are still lying untapped at the Archives of Herstmonceux and Royal Astronomical Society (London). On the basis of some selected ones we intend to treat this topic in detail elsewhere.

Calcutta Observatory

This observatory was established by the East India Company following a proposal by V. Blacker (1778-1826), the Surveyor General of India, to start an astronomical survey of Bengal in order to supplement the surveying by triangulation method. To begin with, the observatory was equipped with[215]

(i) a transit telescope of 5 feet focal length;

(ii) a zenith tube; and
(iii) a Kater's pendulum.

But J. A. Hodgson (1777-1848), one of the first observers who used these instruments had complained: "The instruments..may..be considered as mere playthings so far as making further difficult investigations—in the high science of astronomy.."[216] is concerned. So a few more instruments were later added, namely a transit of 36″ length, an 18″ altitude and azimuth circle and an astronomical telescope of 4½ feet focal length, in order to perform, for instance, eclipse observations. However, as Col. A. Waugh (1810-1878) also pointed out, the "observatory had no pretentions....be considered a metropolitan institution nor was it at all fitted..to investigate questions of high scientific research. It was strictly an *appendage* to the Survey Department...and as such it has fulfilled the object of its institution".[217]

At this observatory Blacker, Hoogsun and a Swiss observer named Vincent Rees performed astronomical observations. An Indian, Sayyid Mir Mohsin (1778-1826) of Arcot in South India was the incharge of instruments. In the words of Sir George Everes, Mohsin had "both genius and originality".[218] A theodolite assembled by him is still preserved at the Victoria Museum, Calcutta.[219]

Hodgson, who was a very keen observer, recorded the eclipses of Jupiter's first satellite and lunar transits.[220] With him, however, the observatory lost its driving force and was then confined only to routine time recording and meteorological observations.[221]

Royal Observatory at Lucknow

The first historical reference to this observatory, which was established in 1832 by King Naṣīruddīn Ḥaydar (who reigned in Oudh 1827-37) is to be found in a report of 1851 of the Royal Astronomical Society (hereafter abbreviated as *RAS*).[222] Thurnton wrote:[223] "Lucknow may be regarded as entitled to an honourable distinction among Indian cities in possessing an observatory".[224] In the historical chronicles following that of Thornton one finds only a very brief reference to the observatory building: *Tārewālī Kothī* ("the star house")[225,226]. Even Markham[227] in his excellent *Surveys* dealt with this observatory by just half a page. Only in 1955 Phillimore[228] gave a few details. His information is mostly based on material published in the journals of Royal Astronomical Society and the Asiatic Society of Bengal.

So far as we know to date, a detailed history of this observatory was written for the first time by us.[229] The historical account of Kamāluddīn Ḥaydrar[230] alias Muḥammad Mīr in Urdu is brief, concerns only with the establishment of the Observatory and is in an old style, i.e. without reference to contemporary source-material; it is rather personal. Our account, both present and previous, is based primarily on unpublished historical records.

Establishment

The observatory, as mentioned above, was established by king Naṣīruddīn Ḥaydar who in 1831 sent the following communication through the Resident of Lucknow to the then Governor General of India, Lord Wiliam Bentnick:[231]

> "As my mind is always bent on promoting diverse enlighted arts and sciences which are replete with good and possess salutary advantages to the wise and to the public at large, it is my wish to establish an observatory in the metropolis of Lucknow and to appoint for its superintendence and establishment Capt.

Herbert who from his works and publications professes great experiences in these matters and is eminently skilled and qualified in the knowledge of astronomy......[232] He will receive Rs. 1000 monthly as his pay and Rs. 700 per mensom for the erection of the observatory and carrying its business."[233]

In founding the observatory the king had two objectives:

"To establish an observatory upon a liberal scale worthy the wealth and importance of the Government as well for the advancement of the noble sincerely new discoveries as for the defusion of its principles amongst the inhabitants of India, for the establishment is intended to embrace translation[234] into the native language and to instruct the inhabitants here. It is contemplated to deliver lectures upon astronomy to the students of the College and to select talented youth for instructions in every branch of the science....observatory instruments I believe to be commissioned from England. The officer to be placed in charge of the Observatory at Lucknow may correspond with the observatories of Europe and contribute to the advancement of astronomy by affording a consecutive series of important observations.[235]

We have given here a rather long quotation, so as to clarify the primary aim and attitude of the king. We shall refer to this point again in the last subsection.

The Governor General of India welcomed the king's suggestion very much and agreed to the appointment or transfer of Capt. Herbert, who on joining the king's service planned and supervised the construction of the observatory building and also ordered Troughton and Simms' astronomical instruments from England.[236] Unfortunately due to his sudden death[237] in 1833 the construction work at the observatory was held up till the appointment of Maj. Richard Wilcox (1802-1848) in 1835.[238] The following accounts, especially that of the astronomical work done in the observatory is based on the *unpublished* reports of Wilcox which he submitted to the then Governor General of India through the Resident of Lucknow, during the period 1840-1848.[239] They are as follows, their exact reference is given in the Bibliography:

I. Oct. 2 (1840),	II. April 1 (1841)
III. Oct. 1 (1841),	VI. Jan 18 (1844)
V. Feb, 25 (1845),	VI. July 9 (1845)
VII. Mar. 24 (1848).	

In the following we shall refer to these Reports by their Roman numbers only. We may mention that the gap between 1841 and 1844 was due to the return of Maj. Wilcox to his corps for active military service.[240]

Equipment

According to the report of the *RAS*, Lucknow Observatory was "certainly the best-equipped observatory in India".[241] In fact, its equipment consisted of the following instruments:

(i) A mural circle of 6 feet on which later a collimating eye piece invented by T. C. Taylor (of Madras Observatory) was mounted.[242]

(ii) An 8 ft transit.

(iii) An equatorial of more than 5″ aperture with the focal length of the telescope equal to 9 ft and the diameter of the hour circle of 2 feet.[243]
(iv) Astronomical clocks by Molyneux.

As to the quality of these instruments Wilcox remarked: "The Meridian instruments are upon the same scale as those at Greenwich, on the model of which they were indeed constructed by the same makers.[244] The Surveyor General of India even went a step further in praising the instruments. He wrote in 1852:"....I consider Lucknow instruments valuable and perfectly sufficient for a first class observatory. In fact they are *far superior to the apparatus in the Madras and Bombay Observatories*". [245] two claimants for these instruments appeared on the scene: Andrew Waugh, who wished to have an observatory at Calcutta "staffed and equipped from Lucknow, provided the instruments could be obtained free of charge"[247] and Capt. W. S. Jacob, who after reading the report of the *RAS*,[248] expressed his wish to obtain those instruments for the Bombay observatory.[249]

Astronomical Work

The programme of work which Wilcox chalked out for the observatory was conceived by him presumably in consultation with various astronomers, since then and later on he was in active professional correspondence with his contemporaries.[250] Extracts from his letters written to a member of *RAS* dated Jan. 7, 1846 and Jan. 22, 1847 were published in the above-mentioned report of *RAS*. In one of these Wilcox referred to an exchange of a letter with George Airy, This correspondence is extant in Airy's paper at the archives of Herstmonceux. In his letter dated Nov. 18 (1840), Wilcox asked Sir George, for instance, about

> ".....the manner with reference to what is being done elsewhere these instruments may best be employed for the interests of science and as there is no one so capable as yourself of answering this question I venture to put it to you in hopes that you will favour me with your advice...."

In his reply Airy suggested to Wilcox to take advantage of his southern latitude in order to observe the planets during day-time and particularly to watch the smaller planets which should be better visible at Lucknow than in Europe, due to the clearness of the Indian sky.[251]

The following astronomical observations were performed at Lucknow by Wilcox and his Indian assistants:

1. Major planets during 5 a.m. to 11 a.m.;[252]
2. Smaller planets: *Ceres* and *Vesta* and occasionally *Pallas* and *Juno*[253]
3. Eclipses of Jupiter's satellites;[254]
4. Occultations of stars by the Moon;
5. Meridional observations of the "stars of the nautical almanac,......and a large number of small stars taken from the catalogues of the Astronomical Society and from those of Piazzi and Bode"[255] and also "reobservations.. of the stars of the third and fourth volume of Mr. Taylor's Madras Observations."[256]

Unfortunately none of Wilcox's observations (completely reduced for the years 1841-43) was ever published, however hard he tried. He corresponded with the

secretary of the *RAS*[257] about this problem of publications, discussed it several times at length in his reports and even succeeded in securing Rs. 6000/- for publications from the king.[268] but in vain. Even after his death and the abolition of the observatory his wish to get at least the reduced observations printed could not materialize, although influential people like Dr. A. Springer, principal of Delhi College, Delhi made efforts to get it done.[259]

We would like to add here a few words about the team of Major Wilcox. It comprised two Indian assistants: Kalee Charan and Ganga Pershad, headed by a Greek called Kallanus, who formerly served in the great Trigonometrical Survey of India Wilcox expressed himself "....highly satisfied with the zeal and ability of my native assistants."[260] "....One could not wish for better observers than our educated lads turn out...."[261] Besides these technical hands there was also the afore-mentioned historian Kamāluddīn Ḥaydar who translated scientific works into Urdu, for instance Rev. Samuel Vince's *The Elements of Astronomy*,[262] or Lord Brougham's *Preface to Natura-Philosophy*, of the Library of Useful Knowledge,[263] or Astronomy by Brinkley.[264]

Abolition of the Observatory

On Oct. 28, Wilcox died.[265] The King of Oudh, Wajid Ali Shah (reigned 1847-56) ordered the abolition of the Observatory on Jan. 20, 1849.[266] The King justified it by claiming that "the great outlay incurred in maintaining it has produced no advantage whatever either to the state or to the people and learned of Oudh.[267] This reasoning is corroborated by Ḥaydar in his History, who further adds that according to a report to the King "the Europeans and not Indians are benefitted by this observatory."[268] However we may mention here another viewpoint also. The Resident at Lucknow, Lt. Col. W. A. Sleeman, claimed that the real reason for the abolition was the annoyance of the King at many remarks made by Ḥaydar in his History of Oudh.[269]

On the request of Col. A. Waugh, Cap. Strange visited Lucknow in 1855 for inspecting the instruments and records.[270] According to him the instruments were preserved well but required cleaning. In fact they were in such a good condition that within a few months a good astronomer could bring them in operation, added Cap. Strange. He therefore strongly pleaded for the resumption of work at the observatory by appointing an astronomer. He also found the records of observations *reduced* and *excellent*.[271] Again, he wished for the rescue of the observation records from the attack of white ants. The apathy of the Governor General is clearly demonstrated by their indecision to support the astronomical work at the observatory.

The result was its expected destruction in the Indian War of Independence in 1857 as reported by James Tennant.[272] Further, Markham noted that "all the work of this once first class observatory has been lost to the World, and its records have perished without rendering any result to science.[273]

Despite the above reports, we tried to search the original records of the observatory at Royal Astronomical Society and Royal Society of London. We could however, find in 1977 only at the Library of the Royal Society daily magnetic and meteorological observation of the years 1942-43 of the Lucknow (Magnetic) observatory.[274] Note, that Cap. Strange actually saw the "unsigned duplicate sheet" at the observatory

in 1855, [275], Haydar in his *History* writes, that at the time of abolition "a large number of school books were auctioned for Rs. 1300 and many of them were acquired by Dr. Sprenger and Wilson."[276] Since the former knew very well the value of Wilcox's observational work, and the latter was a trustee of King's grant of Rs. 6000 to Wilcox, for the printing of the observations,[277] it is most unlikely that the register of observations were not secured by them. We conjecture that those observations of 1841-1843 might be extant either in Sprenger's papers or with Wilcox' family.[278] Optimistically, we are stil in search of those observations,

TRAVANCORE OBSERVATORY

In 1836, on the suggestion of the Resident Gen. Stuart Fraser, an observatory was establish at Trivandrum by the Raja of Travancore, Rama Vurmah,[279] who was famoused for his love of learning and desired "that his country should partake with European nations in scientific investigation".[280] The building of this observatory was planned aud erected by Capt. Horsley (Madras Engineers) and was completed in 1837. Raja Vurmar appointed the astronomer and meteorologist John Caldecott (1800-1849) as derector of his observatory. Actually Caldeeott, who was working before this appointment as commercial agent to the Travancore Government at the port of Alepy, had been the first who "..pointed out to General Fraser..the advantages to science to be derived from the establishment of an observatory at Trivandrum".[281]

Caldeoutt started making observations in July 1837, to start with using his own instruments. However, in the following years on the advice of Raja Vurmah he went to Europe for the purchase of a "permanent instrumental outfit".[282] As a result of Caldecott's efforts the observatory was equipped with the mural circles by Simms and Jones respectively, a transit and $7\frac{1}{2}$ feet equatorial by Dolland, an altitude and azimuth instrument and a few astronomical clocks.[283]

With the aid of an Indian assistant, who was trained under T. G. Taylor at the Madras observatory, Caldecutt collected an enormous amount of astronomical observations which were forwarded by him to the Court of Directors of the East India Company and the Royal Society. His observations comprised also the computed elements for the comets of 1843 and 1845,[284] the solar eclipse of Dec. 21, 1843 which he observed near the source of the Mahe river where ,'it just fell short of totality but offered a beautiful view of Baily's beads".[285] All these astronomical and also other physical observations[286] brought him recognition. Already in 1840 he was elected a fellow of the *RAS* and also of the Royal Society. Unfortunately inspite of his utmost efforts he did not succeed in gatting his observations published. To that end he even made a journey to England in 1846, but in vain.

When Caldecott died in 1849, the observatory was for a short time under the supervision of Rev. Sperschneider, till John Allan Broun joined as its director in 1852. Broun was primarily interested in meteorology and particularly in terrestrial magnetism.[287] Therefore he later on devoted himself solely to magnetic observation for which he set up a special observatory at Agustia-Malley within three years of his joining the Trivandrum observatory. His extensive meteorological and magnetic researches were later published by him.[288] After Broun's departure in 1865 the then Raja of Travancore decided to abolish the observatory.

Poona Observatory

At Poona a small private observatory was established in May 1842 by Capt. W. S. Jacob (1813-1862). The octagonal shaped building of the observatory was done in brick and had a folding roof instead of a dome.[289] Jacob equipped this observatory with a 5 feet equatorial of Dollond.

During 1845-1848, working at his observatory he observed, for instance, the eclipses of Jupiter's satellites, in order to determine particularly the longitude of Poona, and he also carried out observations of Saturn's rings. All those observations he communicated to *RAS*.[290] Jacob's main interest, however, lay in the observation of double stars of which he also compiled a catalogue. Actually he became famous for that catalogue of 244 binaries, also for the calculation of the orbits of a number of binaries and particularly for the triplicity of Scorpii in 1847.[291] His work was recognized by his eldction to the Fellowship of *RAS*.

In 1848 Jacob was appointed director of the Madras observatory in which capacity he worked for 11 years.[292] Since the climate of Madras did not suit him, he cherished the desire to have a bigger observatory set up at Poona or Bombay. Already in 1852 he wrote in a letter to *RAS* that the climate of Poona is the best, "where the air is cooler and the climate less adverse to exertion", and that even the climate of Bombay is "superior to that of Madras". He therefore proposed that "no doubt it would be an advantage to science if that (i.e. then Bombay observatory) were made the principal observatory.[293] To that end he also suggested that the instruments of Lucknow Observatory (after its abolition) be transferred to Bombay. On resigning from the Madras observatory because of ill-health he must have actively worked for the realization of his afore-mentioned wish and in fact succeeded in obtaining in 1862 a grant of the British Parliament worth £1000 to build an observatory at Poona at a height of 5000 feet. On returning to India he purchased a 9 inch equatorial from Lerebours for his observation but 8 days after arriving at Bombay he died in Poona on Aug. 16, 1862. Thus his desire "that an astronomical observatory should be established in the Western Presidency....(was) never fulfilled."[294] Jacob's private observatory completely lost its stimulus after his death. Actually so far as the promotion of astronomy in Inida is concerned this observatory did not play any significant role.

Takhta Singh Ji Observatory

The spirit behind the establishment of an astrophysical observatory at Poona was actually a Parsi physicist Kavasji Dadabhai Naegamvala (1857-1938). Naegamvala belonged to an illustrious family of Parsi contractors,[295] He was educated at the Elphinston College (Bombay), from where he passed his B.A. (1876) and M.A. (1878) in physics and chemistry winning the Chancellor's gold medal for the year 1878. In the same year he was nominated a senior Dakshina fellow of the College. He secured the first lectureship in experimental physics instituted in 1882. From 1881 to 1912 he was a nominated Fellow of the University of Bombay. In 1888, he was transferred to Poona to the College of Science (now College of Engineering) as a professor of astrophysics[296] and in 1900 he was nominated as Director of *Maharaja*

Takhtasinghji Observatory, Poona. Naegamvala's astrophysical work[297] was recognized internationally by his election as the Fellow of Royal Astronomical Society.[298]

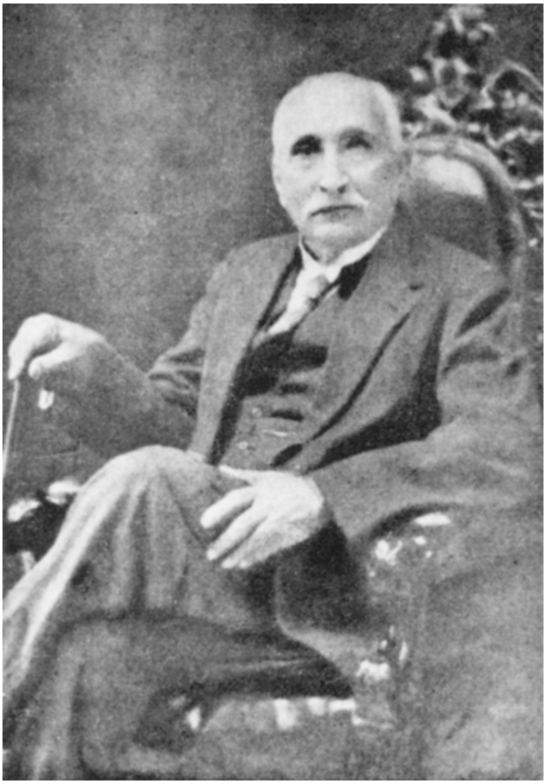


Fig. 12.2 K. D. Naegamvala

The Establishment

In October 1882 Maharaja Takhta Singhji of Bhavanagar visited the Bombay University. Naegamvala represented to the Raja "that adequate means for the pursuit of spectroscopic investigation did not exist in any of (the) Colleges affiliated to the Bombay University and that Elphinston College would be prepared to organise a spectroscopic laboratory, if provided with a sum sufficient for the purpose."[299] The Raja offered a sum of Rs. 5000 and also hoped for a matching grant by the Government to establish such a laboratory. His motivation was two-fold:[300]....on one hand I shall have the satisfaction of knowing that I had done something to supply a very desirable means for study of an important branch of science. I shall on the other hand, have the gratification of thinking that it has permitted me to perpetuate the momory of my present visit......". By a strange coincidence, a spectroscopic observatory instead of a laboratory was established.

Soon after the discovery of solar spectral lines by Fraunhoffer (ca 1812-1814), their explanation by Kirchhoff and Bunsen (about 1859) the spectroscopic technique

was applied to the stars and planets by W. Huggins (in England), H. C. Vogel (in Germany) and Father A. Secchi (Rome)..[301] The latter had contacts with Father Lafont, who was the director of St. Xavier's College Observatory at Calcutta (established about 1875).[302] Only spectroscopic laboratory in India was then at Calcutta where Fa. Lafont was engaged in studies in solar[303] and stellar spectra evidently with the aid of a telescope. It was therefore natural for Naegamvala to visit that laboratory at Calcutta, in order to familiarize himself with the spectroscopic apparatus. Celestial spectroscopy was then the frontline experimental physics, also called Astronomical Physics.[304] Evidently Naegamvala became interested in a spectroscopic observatory. He then communicated his ideas to Principal Wordsworth and got dimself recommended for visiting various laboratories and observatories in Europe by Father Lafont and Father Deckmann (Prof. of Physics at St. Xavier's College).[306]

In 1884, Naegamvala proceeded to Europe "on leave without pay" and a grant of Rs. 10,000 to select apparatus in consultation with the Committee on Solar Physis and the Astronomer Royal).[306] However he first visited several astronomical observatories, "at College Romano at Rome, Astrophysical Observatory at Potsdam, New Observatory of Astronomical Physics..in the domain of Meudon near Paris" and surely Lockyer's Solar Physics Observatory at South Kensington, where particularly he took a training in handling the relevant apparatus.[307] Naegamvala compiled a list of equipment, and got it approved by Astronomer Royal Sir W.H.M. Christie, and returned to India. His ideas to establish "an astrophysical observatory in India at future date" crystalized further by visiting the above-mentioned European Observatories. To start with, he attempted to shift the site of the observatory from Bombay to Poona at the College of Science (presently College of Engineering). He held simultaneously the posts of the curator of the observatory and lecturer in astronomy and optics at the College of Science, Poona.[308]

The Equipment and Astronomical Work

By the end of 1888 the Observatory was ready and Neagamvala announced its establishment by writing to *RAS*.[309] According to him the principal instruments were then: 16 ½ inches silver-on-glass Newtonian by Sir H. Grubb, with a 4" finder attached, an equatorial reflector by Cooke, and several spectroscopes by Grubb, Hilger, Browning.[310] In the following years the equipment was added and continuously improved: The 16½ reflector "was adapted both for visual and photographic work and supplied with electric control, a 12″ siderostate by Cooke and an 8″ lens by Grubb for solar spectroscopic work, also a 3″ transit and a Morse-type chronograph, a sidereal clock, by Cooke.[311]

It should be noted that this equipment was the most modern one at that time in India. Even the Madras Observatory did not possess such instruments for astrophysical work; Michie Smith was then only making efforts to establish a solar or astrophysical observatory at Kodaikanal.[312] Naegamvala was doubtless well aware of the excellent quality of his equipment. He wrote to Sir Christie:

> "My earnest desire is that this splendid equipment that I have managed to bring together should not lie idle and that I may be put in a position to make use of it."[313]

In reply Christie suggested :

> "It is very desirable that the fine equipment of the observatory..should be fully utilised as such valuable work might be done with it at a station like Poona near Equator where observations of the Sun, Moon, Planets etc. could be made under much more favourable conditions than in our Northern Observatories. India seems to be peculiarly marked out for observations of the Sun, especially spectroscopic,..".[314]

Following the suggestion of Christie, Naegamvala turned out best work on the observation of the solar chromosphere and corona, at the time of total solar eclipse on Jan. 22, 1898 for which he led an expedition to Jeur (Western India).[315] According to the late M. K. Vainu Bappu (Director, Indian Institute of Astrophysics, Bangalore), Naegamvala's solar work "is the first complete Indian efforts of its kind on record."[316] Fortunately a report of that meticulously planned expedition was printed and is still available.[317] Besides, he communicated also his *Solar flash spectrum* to the *Astrophysical Journal*. The Editor's remarks are noteworthy: "Perhaps the most interesting feature of the photograph is the prominence shown in two lines *H* and *H*-delta, but invisible in *H* & *K* and the hydrogen lines.[318]

Besides the above-mentioned work, Naegamvala indulged also in astrophysical observations. He carried out spectroscopy of Orion Nebula, Nebula H I, 43 Virgini great sunspot group of Feb. 1892, and also observed the transit of Mercury on May 1891, Nova in Perseus on Feb. 25, 1901, and Nebula NGC 6595.[319]

Ironically in the same year 1898, when Naegamvala did his most important work he was critized in India for "failing to produce any worthwhile astronomical research"[320] On the ground that he was simultaneously holding a teaching position at the University of Bombay.[312] As a matter of fact Naegamvala himself was conscious of this problem. Already in 1896 he wrote to Christie:[322]

> "As long as I am required to teach Physics....it would be idle to expect me to have either the energy or time to accomplish anything."

All the same he did stick to his position at Bombay University during his directorship of the Observatory which can be amply understood by the following remarks of Luckyer in his *Report on Indian Observatories* (1898):[323]

> "The chief disadvantages under which scientific men now labour in India are want of promotion and of graded increases of salary throughout their service. Men of Science are after all men, and are no more likely than others to work heartily without any hope of increased pay or advancement, especially when they are reminded by the promotion and increased emoluments granted to those in other branches of the same state service of their own waterlogged condition."

Inspite of his best efforts Naegamvala could not secure a graded post even up to 1899 though the Govt. of India recognised already in 1887 Naegamvala "as practically qualified for a graded appointment".[324]

Along with his two-fold engagement, however, Naegamvala directed the programme of the observatory excellently. Vainu Bappu remarks about his solar eclipse observation:

> "The report of this successful expedition indicates the *great care and thoroughness* that went into the planning of the expedition".[325]

With his work on the solar corona Naegamvala corroborated Lockyer's opinion about him "as the only person in India at that time who was well qualified to carry out worth which investigation into solar physics."[326]

As a matter of fact Naegamvala's astrophysical work was also praised by Huggins (England), Vogel (Germany), Hale (USA) and by Maunder, Vice-President of *RAS*. Further his work was cited in Clerk's *History of Astronomy in Nineteenth Century*, and in the *Progress of Astronomical Photography* for 1895 and 1897.[327] According to one remark, Naegamvala carned a name in three continents",[328] and it was also conjectured that Sir Norman was "of opinion that the claims of Mr. Naegamvala to be the director of the Imperial Observatory of Astrophysics should not be neglected".[329] Notwithstanding all the afore-mentioned admiration of Naegamvala's scientific work and of his talents, it was decided by the Govt. of India to abolish the observatory after retirement of Naegamvala in 1912. The order was carried out, the observatory was dismantled and the instruments were transferred to Kodaikanal Observatory. For lack of time and space we can not go into the background intrigues of the abolishment of that excellent observatory, in which the then Director-General of Observatories, especially the Meteorological Reporter, J. Elliot, and also the Director of Astrophysical Observatory at Kodaikanal were involved.[330]

Miscellaneous Observatories

Observatories at St. Xavier's and Presidency Colleges:

The St. Xavier's College Observatory (Calcutta) was established in 1875 and initially Father Lafont was the astronomer-incharge. As mentioned before, Father Lafont was in close touch with Father Secchi of College Romano and consequently he could establish at the St. Xavier's College (Calcutta) a good spectroscopic laboratory in order to carry out solar and stellar spectroscopic work. As Naegamvala [331] noted, there existend then in India only one spectroscopic Observatory, the work of which consisted of "the delination of the forms of the solar prominences and spots with the object of supplementing..similar observations..(at)..the College Romano." Fa. Peneranda, the Director of the Observatory in about 1891 observed also other phenomena, e.g. the transit of Mercury,[332] observation of several solar eclipses.[333] However later Fa. Francotte shifted to meteorological work, a fifty years report of which from 1868-1918 was also compiled by him.[334]

So far as the equipment of the observatory is concerned it may be mentioned it had then valuable instruments, namely "two 9″ refractor and reflector equitorials also equatorials of 3" and 4", four transits and spectroscopic equipment."[335] The observatory is presently meant only for teaching.

The observatory at the Presidency College was constructed in 1900. It funded by Maharaja of *Tipperah,* who presented 4.5″ Grubb's reflector. Later in 1922 8″ telescope was added. It was a gift from the Astronomical Society of India.[336]

Observatories at Dehra Dun

Built in 1884, the Hennessy Observatory was meant as the large photoheliograph observatory for obtaining 12″ photos of the Sun. It was named after J. B. N. Hennessy who started his survey work in 1844 and by 1883 he became the Deputy

Surveyor General of the Trigonometrical Branch. In 1884 he retired; he was a Fellow of the Royal Society.

The photoheliograph mentioned above was not in operation when Lockyer visited the observatory in 1898. But he found another one in operation, namely Dallmeyer 8″ photoheliograph.[337] Lockyer noted the importance of the observatory (and also one at the Mauritus) for filling the gaps in rhe Greenwhich series.[338] He pronounced his opposition to the shif ing of the observatory at Kodaikanal, as suggested by Elliot, the Meteorological Reporter.

Another observatory built in Dehra Dun in 1886 was named after Maj. General C. Haig (Deputy Surveyor General of the Trigonometrical Branch). To start with, the observatory was meant as a depository of large astronomical instruments for latitude observations. They comprised Ramsden's zenith sector, Strange zenith sector, two astronomical circles and a zenith telescope; all made by Troughton and Simms (London) It may be noted that the meridian of Dehra Dun longitude station passes through the observatory. Both these observatories are no longer in working condition.

THE CONTROL BY ASTRONOMERS ROYAL

The Royal Society

From its inception in 1660-63, The Royal Society at London (hereafter abbreviated as *RS*) was also the chief authoritative advisory body for the British Government in scientific matters of both national and international importance, though actually it was founded for "improving the natural knowledge by experiments". The British Government sought its advice on calendar (in 1751), geodetic and trigonometrical surveys (1784, 1791) and, as mentioned before, in the supervision of expedition for the observations of Venus transits in 1761 and 1769. Fellows of *RS* were also members of the visiting committee for the improvement of Royal Greenwich Observatory (hereinafter as RGO). The *RS* responded to each government request by forming a relevant committee, e.g. a joint permanent solar eclipse committee in which *RAS* and *RS* were involved.[339] Evidently the same procedure was followed for scientific development in India.[340]

The Indian Observatory Committee (IOC) was constituted in 1885 by the President to monitor the efficiency of the Madras and Bombay Observatoriel. This Committee[341] comprised fellows of the *RS* and of the Royal Astronomical Society, and of course, as most important member, the Astronomer Royal himself. In 1897 IOC was merged with a more general (imperial) Observatories Committees (OC), the terms of reference of which were not confined to Indian affairs alone.[342] In 1898 Astronomer Royal W. H. M. Christi was appointed the Vice-chairman of OC.

The IOC and OC played quite an important role in the development of astronomy in India.[343] However, since the most influential and competent member of these committees was the Astronomer Royal, we deal in the following only with his direct influence and control of the development of astronomy in India.

Nevil Maskelyne (1732-1811)

The first contact of an Astronomer Royal with India dates back to Rev. Nevil Maskelyne's directorship of RGO during 1765-1811. His connections with the early

surveyors in India definitely promoted Indian geographical surveying,[344] in the development of which the origin of observational astronomy in India is to be sought. Among those surveyors, to name a few, were the mathematician and astronomer Reuben Burrow (1747-1792)[345] who is known to have been earlier an assistant of Maskelyne, and James Rennel (1742-1830), the "father of (modern) Indian geography", to whom Maskelyne explained the nature of the Indian survey.[346] Later on also Maskelyne kept himself acquainted with the progress of the geographical survey; it was through him presumably that Major William Lambton (1753/6-1820) secured the latest literature on geodesy for his work in India. Perhaps even more important than the professional advice was the encouragement Maskelyne gave to Lambton; Sir C. Everest (1790-1866), Lambton's one-time assistant, related:[347]

> "To this moment I remember well the gleam of gladness with which my old master used to refer to the fact of Nevil Maskelyne's letter. It had reached him apparently in an appropriate hour when he was surrounded with difficulties.. with this solitary exception, until Professor Playfair took the subject up....[348] he was to appearance forsaken of all, and left to struggle alone..whilst his labours were treated by all his countrymen..with the utmost superlative indifference and neglect."[349]

We may recall that it was still during Maskelyne's time that on the initivative of another surveyor, Michael Topping, the first observatory for modern astronomy was established at Madras.

Sir G. B. Airy (1801-1892)

The Astronomer Royal (AR), Nevil Maskelyne was succeeded by John Pond (1767-1837) AR during (1811-1835)—on whose recommendation T. G. Taylor secured the directorship of Madras Observatory.[350] However, presently we do not know whether Taylor had an active correspondence with Pond or Sir Airy, who was in turn the successor of the former, AR during 1835-1881,[351] On the other hand, the excellently preserved papers of Airy at Hersmonceux contain his extensive correspondence with various astronomers in India, for instance, Wilcox, Tennent and quite substantially with Pogson.[352] As mentioned before, AR was one of the most important members of the Indian Observatories Committees and was supposed by E.I. Co. to supervise its observatories in India. All the same Airy's keen interest in or control of the astronomy programme in India is illustrated by a few selected examples in the following.

Let us recall the correspondence between Major R. Wilcox and Sir Airy[354] As a reply to Wilcox's consultation, Airy advised him "as a general rule (to observe) those objects which you find yourself able to measure most easily and most accurately are best worth following.." However he also gave him a definite advice for observations, namely:

(1) "The planets not at opposition but at the earliest and latest seasons when they are observable in the morning....in the evening;"

(2) "The minor planets....eclipses of Jupiter's satellites and occultations of stars by the moon";

(3) "The southern double stars,"

(4) "and all the small stars which are near to or included in Herschel's. Besides he quite modestly added that it was not for him quite easy to chalk out a course for some one else and that his suggestions might be contrary to Wilcox's under standing of the situation.[354]

In later years, however, his ideas developed on different lines, when Lord Cranbor from Indian Office (London) called on him in 1866 and discussed with him the maintenance of Bombay and Madras Observatories.[355] After getting prepared a memorandum on the aims and objectives of an observatory,[356] Airy observed, "that it is owing to the steadiness of plan produced by the definitions of duty contained in the Royal Warrant and Admiralty instructions to the Greenwich Observatory, that the Observatory has been the most useful in the world." And naturally he suggested "a similar document together with provision for the periodical reports," for Madras Observatory.[357]

In that *Code of Instructions* which consisted of nine sections particular stress was laid on the meridian observations, in order to supplement those of Greenwich, Cape of Good Hope and Australian Observatories. Also the Madras astronomers, although allowed to do "special investigations" (i.e. of their own choice), were especially asked"....not to interfere with the regular routine of the observations". Probably in order to ensure the latter it was further asked that "monthly tabular statements of arrears of reduction and publication (i.e. annual volumes and reports) should also be submitted" to the Astronomer Royal.[358] Quite a rigid control no doubt! However POG the Government astronomer at Madras rightly objected to that type of control. He suggested that since.[369]

> "Public opinion would be no check in this country....what then is required is that an annual statement should be drawn up by the Madras Astronomer, to be submitted to Home Government, through Astronomer Royal......An arrangement of this character, while securing the application of a check upon the Madras Observer, would not subject him to a direct pressure from the Astronomer Royal; and I must remark that to place the Astronomer here under direct orders......would cramp the energies of the former, and take away from him that independence of feeling which is essential to a successful follower of Science".

A very sound advice indeed by a real scientist!

Sir W.H.M. Christie

The successor of Airy, Sir W.H.M. Christie, appears to have been unaware of the Code initiated by Sir Airy, According to a remark of Sir Lockyer "The Indian Government believed the Astronomer Royal in England was in overall control of the Indian Observations whereas the Astronomer Royal was equally clear that he had no such responsibility"[360] However, Christie did continue some sort of contacts with the astronomers in India; we have already dealt with his communication (advice) to Naegamvala.[361] He even came to India himself in 1898, heading a solar eclipse expedition, and utilized this opportunity to tour a few Indian observatories, viz. those at Bombay, Madras and Kodaikanal; the establishment of the latter he had effected through the Indian Observatory Committee. On that tour the Meteor-

logical Reporter (also Deputy Director of the Madras Observatory) Mr. J. Eliot looked after him.[362] After his return Christic wrote a *Report on Indian Observatories*,[363] in which he suggested in particular some modifications to Eliot's proposals[364] for the improvement of the work of astronomical and magnetic observatories in India, though agreeing to its acceptance "as a sound basis for the reorganization of Indian Observatories."[36] We shall not go into other details of that important report here but shall confine ourselves to one point only, namely the control, which according to him should comprise:[366] an annual inspection "by a Board of Visitors, composed of Surveyor General, the Meteorological Reporter, a couple of Indian Government officials; and also an annual report to be submitted to committee in England. But Christie was very clear about the independence of astronomers working in India. He further added that "nothing should be done to weaken the sense of responsibility of the Government Astronomer and that he should not be placed under the direction of any other official. He alone should be responsible for making the observations considered advisable and for their discussion and publication."

Sir Norman Lockyer

A more comprehensive report on Indian observatories was however compiled by Lockyer who was not an Astronomer Royal.[367] That report was in response to a request by Indian Office (London) to inspect the Indian observatories on his return from 1898 solar eclipse expedition headed by Lcokyer himself.[368] Lockyer visited all meteorological observatories (Calcutta, Bombay and Madras), magnetic observatory at Bombay, astronomical observatories for time at Calcutta and Bombay, general astronomy at Madras and for solar physics at Dehra Dun and Poona (the director of the latter was Naegamvala). He describes in his report the instrumentation and work of each observatory, gives his own critical remarks about Government scheme, and administration of the observatories, and argues extensively for the establishment of an Indian Solar Physics Observatory at Kodaikanal. Further, he depreciated the non-astronomical routine work at these observatories, expressed his impression of a lack of coordination and control, also of rationalization of work done there. He recommended strongly for the astronomers working at those observatories *more* time to do pure research.[369]

In short, that report along with the one by Christie exercised a very important influence on the further development of modern astronomy in India. In fact, we in India owe much to Lockyer for the development of Kodaikanal Observatory as a Solar Physics Observatory, and which paved its way to become an astrophysical observatory later.[370]

THE CONDITIONS OF SCIENTIFIC WORK

Without going into the details of colonial science policy of the then Government in 19th century India on which some work has recently been done,[371] we outline in the following first the socio-economic conditions in which even the astronomers of European descent worked in 19th century. According to our investigation,[372] the main problems of the astronomers then were,

(i) the emoluments of the astronomers in contrast to administrators;

(ii) the possibility of promotions and a graded service,
(iii) the attitude of the colonial administration towards the scientists and scientific work, *per se*.

The records show that the second government astronomer at the Madras Observatory, John Goldingham, drdwing a salary of 192 Pagoda (1 Pagoda, a gold coin=3—4 Sonat Rupee), concurrently worked for a few years as an architect or civil engineer also, i.e. as incharge of all buildings at Madras town. He was allowed to earn a commission of 15 p.c. on the total cost for building and repair in order to supplement his earning. We have already mentioned another example of K. D. Naegamvala, Director of the Takhta Singhji Observatory at Poona, who was simultaneously working as a Professor of Physies at Bombay University.[373] Evidently such a double employment was due to a low salary structure as corroborated by the following evidence.[374] According to N. R. Pogson—Director of Madras Observatory 1861-1891—the director's salary was raised some time in the eighties of the last century from Rs. 672 to Rs. 800. Yet it was quite inadequate and "not befitting his rank in science". For comparison a principal of a high school then got a salary of Rs. 1000, first class officers of the Trigonometrical Survey of India drew not less than the same amount, while the starting pay of the Meterologist to the Government of India was Rs. 1350. Besides, Pogson's assistants—first his son and later his daughter-were just drawing Rs. 150, "equal, I (Pogson) suppose, to that enjoyed by Governor's coachman or cook, a fifth of that a native or East India Deputy Collector.[375] No wonder Pogson had to earn an extra Rs. 250 p.m. by supervising meteorological observations, which he could ill afford to forego in view of his large family of eleven childrep.[376] Many a time in his letters to Astronomer Royal Sir Geoge Airy, Pogson complained about his low economic position and inferior status to other officers of the Government of India.

A similar opinion was voiced by Sir Norman Lockyer in his Report as quoted before.[377] The policy "of treating its (Govt. of India) scientific savants on a different principle from that adopted in other department", was surely unconducive to the promotion of science. Besides, Lockyer also noted the contempt with which the scientists were regarded by the British Administrators. In fact according to J. F. Tennant, Director of Madras Observatory (1859-1860).[378]

> "..in high Indian circles men of Science arę considered as loafing imposters who trade on the general ignorance at home".

Naturally, Sir Lockyer pleaded for a better status for scientists in India and for the recognition of their work.

So far as the technical difficulties under which scientific work was carried out at these observatories are concerned, we may add the following. Too much routine work like overhauling of ship's chronometers, meteorological and magnetic observations swallowing away the precious time of a good astronomer were probably the main handicraft. It was true for Madras as well as for Lucknow. So much so that the Governor General even ordered an explanation from Col. Wilcox why a meteorological and magnetic register was not kept at Lucknow observatory.[379] Wilcox pleaded "not guilty of any lapse, since he was not aware that meteorological registers were supposed to be a part of his duties. He further argued:" I have not found any instance of their being indebted to any observatory for their meteorological journal......In

short, meteorology is considered quite separate from the science of astronomy.[380] Despite that explanation Wilcox did keep meteorological and magnetic registers and carried out those observations regularly.[381]

It was the same case with Pogson at Madras. He had to do also meteorology for financial reasons, although he was of the opinion that "to require such an officer (an astronomer) to neglect his far higher pursuits and dabble in such comparative trifling as Meteorology is past all endurance". He equated the indulgence of an astronomer in meteorology "as a fall" and lamented at his soiled reputation for the sake of earning a few more Rupees by meteorology.[382] He recommended very strongly that "the astronomer....wherever he may be located should be left alone....Separation from the Meteorological Department of India and perfect freedom from every thing which can interfere with his astronomical duties should be enforced." He bitterly suggested as an alternative that "the observatory should be at once and for ever swept away as a luxury no longer needed."[383]

As a tail-piece it may be added that the recommended separation could be brought about only in Independent India with the untiring efforts of the late M.K.V. Bappu in the seventies, when he succeeded in founding the Indian Institute of Astrophysics, situated now at Bangalore.

CONCLUSION

It is clear from the preceding section that the promotion of the science of astronomy (in fact for that matter any basic science) was not the aim of the British Colonial Government in India, although the Indian mind was quite receptive and anxious to learn the new sciences. We have already cited the example of Raja Jai Singh's use of telescope and his association of Jesuits with the astronomical programme at his observatories. Another example in support of this receptivity is the commissioning by Dānishmand Khān (Mughal Governor of Delhi) of the Persian translation of the works of Descartes and Gassendi, as reported by Jesuit traveller Bernier, who visited India from 1659 to 1667.[384] As a consequence, a channel of communication between India and Europe was developing fairly well in 17-18th century. However with the commencement of the colonization of India by the Europeans: Portuguese, French and English, in the 17th and its intensification in the following century, that intellectual communication between India and Jesuit scholars broke down gradually.[385] The reasons could be: the weakening of the Mughal Central Authority, the rise of local rulers, the political manipulation and military successes of well-organized European colonialists especially British in the disguise of traders, and the resulting chaos in the then socio-economic system. The ensuing situation in turn cut off completely the patronisation of sciences and arts by Indian monarchs and local rulers. Last but not the least, the increasing proselytization activities of several christian missions under the patronage of respective European powers bred distrust among Indians about the selfish design of the Jesuits and other missionaries. It is no wonder tha all the socio-political circumstances arrested altogether even the reception of the secular knowledge from Europe and nipped the buds of the probable flowering of a scientific renaissance in 19th century India.

Modern Astronomy in Persian—the Indian Effort

We have mentioned the programme of translation of European physical sciences into Urdu, which was sponsored by King of Oudh, *Nasīruddin Ḥaydar,* in the first half of 19th century. But a number of works on modern European astronomy were written before and at about the same time, in Persia and/or Urdu. A selected list follows:

1. Muḥammad Ḥussayn ibn 'Abdul Azīm Al-Ḥusaynī Al-Isfahānī d. 1790, *Risāla der ahwāl mulk-i farang wa hindustān* (in Persian). The monograph is an account of author's journey to Europe during 1772-73, manuscript extant at Aligarh, Bombay and Hyderabad.

2. Abu Ṭālib Al-Ḥussaynī, *Risāla dar hay'at-i jadid* (a monograph on modern astronomy in Persian), manuscript extant at Rampur, completed in 1798.

3. Abul Khayr ibn Mawlwī Ghiyāthuddīn, *Majmū'a Shamsi* (a monograph on Corporation system), MS at Bombay, Delhi and Hyderabad. The Persian text was published at Calcutta in 1826, and its Urdu translation in 1843.

4. Anonymous, *Miftāh al-aflāk* (Key to Heavens). It was first published in Urdu at Calcutta in 1833 and later translated ino Persian for scholars in 1847 Wājid 'Al Shâh–King of Oudh's time.

5. Mawlwī Shamsuddīn, *Sitta-i Shamsīya,* a set of six monographs on various sciences, one of which is also astronomy. It is supposed to be Urdu translation from English and was published in 1836.

It is not the place to describe briefly the contents of the above selected monographs. It is enough to add that the above-mentioned works deal quite well the Copernicus' system, Newton's and Herschel's contributions to astronomy. They deal also especially with the telescope. In fact about the same time Herschel's *Principles of Astronomy* was also translated into Urdu. Unfortunately that wave of Persian works on and Urdu translations of European sciences died with the introduction of English language as medium of instruction in Indian schools and colleges. Note that translations into Latin of Arabic[386] and Greek works in Europe during 12-13th century were the pre-requisite for "the revolution in attitude and ideas" during renaissance which Bernal calls "as the first phase of scientific revolution".[387] Thus the imposition of English gave a death-blow to the possible scientific revolution even in its birth.

Summary

As shown in sec. 5, the science policy of the colonial Government in India was not at all conducive for the development of the science of astronomy, carried out even by Europeans at the Government observatories. By its very nature the EICo and later the then Government of India was interested only in the commercial exploitation of India and not in any kind of public services like education etc., apart from the "production" of English knowing clerical staff especially of lower ranks for its administrative machinery. In fact it was a patriotic band of Indians, for instance Raja Ram Mohan Roy (1772-1833) and Sayyīd Aḥmad Khān (1817-98), who relentlessly fought for the teaching of modern European knowledge particularly of sciences in the Indian schools and colleges, since they became quite conscious of the downfall of the indigenous system of education because of its lagging behind with the develop-

ment of knowledge in Europe and also for want of patronage by Mughal Kings, rajas and nawabs. Though the British rulers were thus compelled to introduce sciences like physics and chemistry in the English-medium schools and colleges, yet astronomy was not integrated into that system of education, despite its central role in the curricula of both Muslim (Persian-medium) and Hindu (Sanskrit-medium) indigenous educational instituties. Thus the few observatories established in the 19th century at Madras, Bombay and Calcutta remained in effect *alien outposts of a foreign science.* The directors were naturally all Europeans and almost all Indians employed there were kept as mechanical computers, or for menial work. Not a single government observatory was then attached to any educational institution, apart from the private Takhtasinghji Observatory at Poona College, which was also manoeuvered into abolition after the retirement of its director K. D. Naegamvala, the first astrophysicist of India.[388]

European astronomy in India, inspite of its institutionalization in the sense the establishment of a number of observatories, could not become an integral part of Indian educational system. This British legacy is being gradually eliminated, though with difficulties by those astronomers/astrophysicists who are working at the Indian universities presently. However, this remark does not imply that independent India is still lagging behind the modern developments in astronomical/astrophysical research. In fact India has produced in this century one of the few world-renowned astrophysicist namely, M. N. Saha. Besides, by commissioning two 40″ telescopes (of Carl Ziess Jena) at Nainital and Kavalur, constructing of a 90′ telescope indigenously at the Indian Institute of Astrophysics, Bangalore (first Director, late M.K.V. Bappu,) setting up of telescopes, for radio, millimeter and infra-red spectral regions at Ooty, Bangalore and Mt. Abu respectively, and by launching of the Indian Satellite Programme, modern astronomy in India has already come off age after indenpence.[389] With pride we note that these efforts have been recognised internationally, especially by the election of late M.K.V. Bappu as President of the International Astronomical Union (IAU) for 1979-82, and by the holding of XIX General Assembly of IAU in India this year in November.

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13 ASTRONOMY IN INDIA IN THE 20th CENTURY

J. C. BHATTACHARYYA and A. VAGISWARI

ASTRONOMICAL STUDIES IN INDIA

Interest in astronomy dominated Indian thinking from the very early times. Many references to astronomical events and their interpretations are found in the Hindu, Jain and Buddhist Scriptures. During the period of compositions of astronomical *siddhāntas* (5th to 12th century A.D.) the motions of the Sun, Moon and planets were studied in detail. It is well known that Āryabhaṭa, Varāhamihira, Brahmagupta, Bhāskara I and Bhāskara II made monumental contributions towards the development of astronomy. These early astronomers whose contributions have been discussed in detail in the previous chapters, had influenced the academic endeavours for several centuries. This was followed by a period of relative inactivity till late seventeenth century.

In the year 1609 the optical telescope was discovered in the western world and its extensive use by Galileo revolutionized the study of astronomy. The first major development in new astronomy in India occurred when Father Richaud, a French Jesuit priest used the astronomical telescope for the first time on the Indian soil in the year 1689. He discovered a comet and the binary nature of the bright star alpha Centauri from Pondicherry. [1 2 3] Next important landmark was the work of Raja Jai Singh (1686-1734). He launched an ambitious programme of development of observational astronomy by establishing a chain of 5 observatories at Delhi, Jaipur, Mathura, Ujjain and Varanasi and started accurate observations. These institutions contained enormous masonary instruments many of which were invented by Jai Singh himself. Magnificent in concept, in practice they had little use. It is still a mystery why Raja Jai Singh did not use telescopes extensively instead of the huge cumbersome masonary structures, since some recent studies have shown that Raja Jai Singh was familiar with telescopes and had even incorporated telescopic observations in the compilation of astronomical tables, [4 5 6] The first modern observatory was established in Madras by the British East India Company in 1792. "The East India Company having resolved to establish an observatory at Madras for promoting the knowledge of astronomy, geography and navigation in India, Sir Charles Oakely, then president of the Council, had the building for the Observatory completed in 1792". The first observations were commenced in 1787, through the efforts of William Petrie who had with him two 3″ achromatic telescopes, two astronomical clocks and an excellent transit instrument. This equipment formed the nucleus of the instrumentation of the new observatory which soon embarked upon a series of observations of stars, the Moon and eclipses of the Jupiter's satellites. [7 8 9] For over a century Madras Observatory made systematic measurements of stellar positions and brightness. Goldingham, Taylor, Jacob and Pogson were government astronomers, who dominated

the activity. J. Goldingham was the first astronomer at Madras. His earliest observations made in 1793 were recorded in a manuscript volume where an account of the observatory building was also given. Further observations were published by him in later volumes in 1812 and 1825.[10 11] Taylor completed in 1844 his catalogue of places of over 11,000 stars. [7 12] Jacob's principal interest was double stars, viz. measures of their separation and determination of their orbits. [7 13] From 1861 until his death in 1891, N. R. Pogson entered newer areas of observations. With the help of an 8-inch Cooke equatorial he made discoveries of asteroids and variable stars. [16] Pogson also undertook the preparation of a catalogue and atlas of variable stars complete with magnitude estimates.[14 15] These were edited by Turner after Pogson's death. The discovery in 1867 of the light variation of R Reticuli by C. Raghunathachary is perhaps the first astronomical discovery by an Indian in recent history. [8 17]

After Jai Singh, the Royal patronage for astronomical efforts was taken over in several Indian states in the 19th and early 20th century. The King of Oudh had established an observatory at Lucknow around 1932. The principal equipment here was a mural circle of 6 ft, a 8 ft transit instrument and an equatorial telescope by Troughton and Simms. Wilcox who assumed charge of the observatory made some observations but after his death the observatory was closed down in 1849.

In 1837, the Maharaja of Travancore had founded an observatory in Travancore. It had a transit instrument, two mural circles and an equatorial telescope and magnetic and meteorological instruments. The observatory was, however, wellknown for magnetic observations made by Broun who was the Director from 1851 to 1865. His chief discovery is now hailed as one of the fundamental principles of terrestrial magnetism, that magnetic disturbances on earth are not localized but are a world-wide phenomenon.[8] Broun is also associated with the discovery of the relationship between solar disturbances and subsequent changes in the state of the earth's magnetism in recurrent intervals of 27 days. After Broun's retirement the activity of the observatory was greatly reduced.

Special mention must be made of the observatory started in Poona in the last decade of the 19th century. This was the Maharaja Takhtasinghji Observatory which functioned on modern lines. It commenced work under the direction of K. D. Naegamvala, part of the funds for this observatory coming from the Maharaja of Bhavnagar. The observatory had the largest telescope in the country, a 20″ Grubb reflector.[9 19] The most important work that appeared from this observatory was the observation of solar corona during the total solar eclipse of 1898. The Naegamvala expedition of Jeur and the observation of corona and its spectrum are described in Vol. 1 of the publications of Maharaja Takhtasinghji Observatory.[20] The observatory was closed down in 1912 and the 20-inch reflecting telescope was transferred to Kodaikanal Observatory. [21]

There were three total eclipses with paths of totality across India during the 19th century. The first eclipse was in 1868, the observation of which resulted in astrophysical work of great importance. It was the French astronomer Janssen who,

stationed at Guntur in Madras Presidency, applied the spectroscope to the Sun during the moments of totality.[22 23] He found a spectral line close to and on the blue side of the yellow lines of sodium. This was the first eclipse to be observed with the spectroscope. The hydrogen emission lines seen were so strong that Janssen reasoned that could be seen even without an eclipse. Next day he observed again and the bright lines were there just as he had predicted.[14] There were several eclipse teams scattered over the path. The Madras Observatory had two teams one at Vanpurthy and the other at Maslipatnam where Pogson was in charge. The English expedition was led by J. F. Tennant at Guntur who also made the discovery of the D3 line.[25] Sir Norman Lockeyer attributed the line to a hitherto unknown element christened as "helium". Helium was discovered in the laboratory 27 years later by Ramsey.[24]

The eclipse of 1871 had a path of totality passing over Ootacamund and Pudukotai near the southern tip of the country. Janssen, at this eclipse, reported the discovery of dark absorption lines in the coronal spectrum. This was the occasion when what we term the F-corona was first seen.[9]

The next important eclipse in India was in January 1898. Numerous expeditions from different countries were scattered along the path of totality from Ratnagiri to Sahdol in former Vindhya Pradesh. Naegamvala had organized a very comprehensive study of both chromosphere and the corona. The report of this expedition indicates the great care and thoroughness that went into the planning of the expedition. The other two important teams were led by Evershed and Lockeyer. All observers obtained flash spectra during this event.[9 23]

ASTRONOMY DURING THE FIRST HALF OF THE PRESENT CENTURY

Major advances in astronomical research in India were made by Indian scientists in the present century. This was possible due to a fortuitous combination of scientific developments and astronomical events. Naegamvala's observation of the solar eclipse of 1898 broke the psychological barrier of Indians achieving scientific objectives. The appearance of Halley's comet in 1910 created widespread new interest in the subject. The establishment of Kodaikanal and Nainital observatories rekindled the interest in astronomical observations. In addition, the spread of science education in the universities fostered a general awareness of celestial phenomena. Detailed descriptions of development of astronomical activities are described in the following sections.

KODAIKANAL OBSERVATORY

An interesting and unusual factor which contributed partially to the establishment of the Kodaikanal Observatory was the Madras famine. Pogson had thought earlier of an observatory on Palani or Nilgiri Hills, particularly for the photographic and spectroscopic observations of the Sun and stars, but no action ensued in his life time. However, the Madras famine of 1886-87 which occurred due to the failure

of the monsoon rains gave a fillip to the establishment of a solar physical observatory. A commission of inquiry which was appointed by the Government to investigate the cause of the famine brought to the notice of government a correlation between the seasonal distribution of rain and sunspot periodicity and recommended that the observatory should investigate this problem. When C. Michie Smith was appointed as Government Astronomer in 1891 the project began to take shape. In 1895, he selected Kodaikanal in the upper Palani Hills as the location for establishing an observatory. The construction work was taken up in 1899 and in the same year the administrative control of this observatory was transferred to India Meteorological Department. This observatory started functioning in 1900. Systematic work in seismology and meteorology was taken up and as soon as the necessary instruments could be erected the study of sunspots, solar photography, prominences and sunspot spectra was commenced.[26] The first solar observations were taken at Kodaikanal in 1901 and spectroscopic astronomy was planned for the observatory. While the two observatories functioned together under the control of a Director at Kodaikanal, work at the astronomical observatory at Madras was confined only to the measurement of time. The new observatory at Kodaikanal had a wide array of spectroscopic equipments specially acquired for solar studies. There were instruments to visually examine the prominences around the solar limb and the spectra of sunspots. Photographic studies included daily white light photography of the solar disc and monochromatic chromospheric pictures with the spectro-heliographs in the light of the lines of ionized calcium and of hydrogen. The uninterrupted series of photographs continues till the present day and forms one of the most unique collections of a record of solar activity available anywhere in the world.[9] Only two other institutions, the observatory at Meudon in Paris and the Mount Wilson Observatory can boast of a comparable collection.[27]

John Evershed, who had been earlier involved in the discovery of ultraviolet spectra of prominences during the total solar eclipse of 1898 in India, joined the observatory in 1905 and later became its Director in 1911. He instituted a programme for photographing the prominences and for systematic investigations of the spectra of sunspots.[28, 29] These observations resulted in two important discoveries in solar physics, viz. (1) the radial motion in sunspots known as the Evershed effect[30, 31, 32, 33] and (2) nature of the sunspot spectra.[34] Evershed found that many Fraunhofer lines in the sunspot spectra were systematically shifted towards the red and he was further able to show that these shifts were due to Doppler effect. His success in observing and measuring the radial motions which had hitherto escaped observations was due in part to the careful methods he had adopted in measuring small shifts in sunspot spectra, and in part to the spectrograph he built with a 6-inch grating given to him by Michelson. He continued his work in this field both at Kodaikanal and also at the temporary field station in Kashmir. For measuring the minute shifts of the spectral lines Evershed devised a positive and negative method of spectrum plate measurement and constructed a special measuring microscope for this purpose. This formed the basis of spectral compensators in use at several observatories. The idea was further developed by R. Leighton fifty years later when he produced the Doppler and Zeeman spectroheliogram by his photographic subtraction technique.[35, 36, 37]

The nature of sunspot spectra was engaging the attention of astronomers at that time. Evershed simultaneously with Fowler, Hale, Mitchel and Adams reached the conclusion that the spectra of sunspots were similar to those of stars of spectral class K.[23] C. Nagaraja Iyer at Kodaikanal obtained reversal of the D3 line of helium in the penumbra of spots.[38] Evershed proved that all spark lines are weakened in the spot; a fact which was later explained by the ionization theory. Several other papers by Evershed published from Kodaikanal call for mention. High dispersion spectrograms secured of Venus showed that the line shift was unaltered when light reflected from the far side of the Sun was examined. In 1918, the spectra were obtained of Nova Aquilae during the first two weeks after the outburst of radiation.[39] Evershed deduced from the initial high outward velocity of gases, compared with the velocities in prominences, that only the gases of the star's original chromosphere would be driven out if the repulsive force was light pressure. He emphasized the presence of sharp non-displaced absorption of H and K lines in the spectrum and identified their source with interstellar gas clouds. A high dispersion spectrogram was secured of Sirius and Evershed pointed out the large widths of the absorption lines especially of hydrogen.[40]

Evershed measured the limb spectra and compared them with the spectrum at the centre of the disk for a study of solar rotation and of the shift toward the red end of lines at the limb. At one time he was inclined to attribute this shift to motion, but later when Einstein gravitational displacement was recognized as a factor to be taken into account, Evershed made further studies of the question.[41] His final view was that the Einstein effect accounted for most of the red-shift at the limb but there remained a definite unexplained residual shift.

Evershed also participated in the observations of the solar eclipse at Wallal, Western Australia. The main purpose of the expedition was to photograph the star field surrounding the Sun on a very large scale and to determine the deflection of light near the Sun by comparison with photographs taken later with a star field at the same altitude. But due to some defects in the instrument the experiment failed.[28, 42]

T. Royd's early papers dealt with periodicities in prominences and their distribution on the solar disk. He compared solar observations to laboratory spectroscopic work and attempted to deduce the variations of density over the solar disk. His most important contribution in this field was the measurement of lines at the extreme limb of the Sun observed at solar eclipse of June 19, 1936. He was a member of the team sent to Japan and the only one to get any results as the sky was clear only for a short while.[23, 43, 44]

A. L. Narayan's early work at Kodaikanal was in the field of atomic spectra and a number of papers were published by him and his co-workers. Among them are the spectra of doubly and trebly ionized lead, the hyperfine structure of indium and thallium, arc spectrum of arsenic, the fine spark spectrum of bromine, the resonance lines of thallium and their probable absence in the Sun.[46] A photoelectric photometer for the direct measurement of the intensities of Fraunhofer lines was constructed by Narayan and the profiles of a few Fraunhofer lines near the centre and the limb of

the Sun were studied by him and his co-workers. Among the investigations carried out under the direction of Narayan may be mentioned the studies on band spectrum of phosphorous which led to the conclusion in favour of the existence of the P_2 molecule in the Sun.[26 45]

NIZAMIAH OBSERVATORY

Nizamiah Observatory which was started in 1908 celebrated its Platinum Jubilee in 1983 and can justifiably be proud of a distinguished history. The observatory came into existence in 1901 when a rich nobleman of Hyderabad, Nawab Zafar Jung acquired a 15-inch Grubb refractor from England and started a private observatory at Begumpet, Hyderabad and sought the permission to call it Nizamiah Observatory after the 6th Nizam of Hyderabad, Nawab Mir Mahboob Ali Khan Bahadur. In 1908 the administration of the observatory was formally taken over by the Government and soon after it was involved in a memorable programme of mapping the sky.[47] In this international programme of carte-du-ciel, 18 observatories with instruments of similar type participated. They were entrusted with photographing different zones of the sky. The Nizamiah Observatory observed $-17°$ to $-23°$; later it was also alloted the zones between $+39°$ to $+36°$ which was originally given to Potsdam.[48] This was carried out with an 8-inch astrograph built by Cooke and it was conducted under the guidance of three Directors-Chatwood (1908-1914), Pocock (1914-1918) and T. P. Bhaskaran (1918-1944). Twelve catalogues comprising observations of 8,00,000 stars were published. During Chatwood's time the construction of astrograph was taken up and the astrograph was installed by the end of 1909.[47] After this, he initiated the work on astrograph catalogue. This work was continued by Pocock who did much towards the completion of the catalogue covering the zones $-17°$, $-18°$ and 159 plates in zone $-19°$, 101 plates in $-20°$.[49] In addition to the work on astrographic catalogue, he studied Nova Aquilae, sunspots, relation between the elements of planets and satellites.[50] Under the enthusiastic guidance of T. P. Bhaskaran, the next director, the programme for the zone $-19°$ to $-23°$ and $+36°$ to $+39°$ was completed. He was mostly a practical astronomer.[51] The 15-inch Grubb refractor of the observatory was erected under his supervision in 1922. He initiated a programme of observations of variable stars with faint minima with this instrument. During the time of Bhaskaran, the observatory which was under the control of the finance department since its take over by Nizam's Government in 1908, was transferred to the Osmania University.[47] M. K. Bappu who was an astronomer at the observatory had contributed a large number of variable star observations. The availability of a spectroheliocope in the mid-forties and a blink comparator extended the sphere of activity of the institution. Proper motion studies of stars in Hyderabad astrographic zone were commenced. In 1944 when Akbar Ali (1944-1960) succeeded Bhaskaran, a programme of double star measurements formed an important addition to the activity. During Akbar Ali's directorship, double star measurements formed an important programme.[52] It was mainly through his efforts that the order for 48-inch telescope was placed and later acquired. He saw the need for a photographic coverage of larger areas of the southern sky and wanted to introduce the new study of photoelectric photometry and made out a case for a Baker corrector for the 48-inch

telescope. Akbar Ali was a man of vision and enthusiasm and encouraged young astronomers. One of his proteges was M. K. V. Bappu. In the words of Bappu, Akbar Ali represented 'the best in Islamic culture'. The study of comets, variable stars, lunar occultations, solar activity, study of proper motion of the clusters were pursued at the observatory.

Astronomy in the Universities

In the first half of the twentieth century, outside the Kodaikanal Observatory, astronomical work was mainly alive in some universities. An account of the activities of Osmania University, Hyderabad has already been given in the previous section. Activities of other university centres are described in this section.

1. *Calcutta University*. In the second decade of the present century, Calcutta University was the prime centre for physics in the country. Prof. C. V. Raman, the Palit Professor of Physics was very keen on astronomy and encouraged his students and colleagues in astronomical work. Major impact produced in astrophysics during this time was by a young theoretical physicist M. N. Saha. Saha's greatest contribution is undoubtedly the postulation of the theory of thermal ionization and its application to stellar atmospheres. The equation that goes by his name was first given in the paper "On ionization in the solar chromosphere" published in the *Philosophical Magazine* of October 1920. Saha considered the state of excitation and ionization in stellar atmospheres to be functions of the temperature and pressure of the atmosphere. This was an important application of Bohr's atomic theory to astrophysics and also provided a theoretical basis for the work done by earlier astronomers like Pickering at Harvard Observatory. Spectral classification provided by the Harvard group represented a temperature classification but they had to wait till Saha provided an explanation in 1920. The theory of thermal ionization introduced a new epoch in astrophysics by providing for the first time, on the basis of simple thermodynamic considerations and elementary concepts of quantum theory, a straightforward interpretation of different stellar spectra in terms of physical conditions prevailing in stellar atmospheres. Struve in his book *Astronomy of the 20th Century* has quoted an interesting anecdote. Saha first submitted the paper embodying his theories to the *Astrophysical Journal* whose editor rejected it. His theory was published finally in the *Philosophical Magazine*. The next editor of *Astrophysical Journal* found Saha's manuscript in a box containing the rejected papers. H. N. Russel, commenting upon Saha's theory said, "The principles of the ionization theory will evidently be of great importance throughout the whole field of astrophysics and Dr. Saha has made an application of the highest interest to the question of the physical meaning of the sequence of stellar spectra."[53] Saha was also one of the first few to suggest the importance of UV observations and the necessity of going out of the atmosphere for understanding the stellar mechanisms better.[54]

Besides having prestigious departments of physics and mathematics, the Calcutta University did not have any organization for astronomical studies. Optical telescopes were available in two small observatories of the Presidency College and the St.

Xavier's College. Important theoretical work made by scientists connected with the university included besides Saha and Raman the names of N. R. Sen and N. K. Chatterjee.[58]

2. *Allahabad University.* An active group of astrophysicists grew around M. N. Saha when he moved to Allahabad from Calcutta in 1925. He started work on laboratory astrophysics and encouraged a strong theoretical group in the subject. Some of his associates like P. L. Bhatnagar, A. C. Banerjee, H. K. Sen, D. S. Kothari and R. C. Majumdar all started their career in astrophysics from this university. P. L. Bhatnagar and H. K. Sen worked with D. H. Menzel on stellar interiors.[59]

Theoretical work on the physics of stellar interiors was undertook by D. S. Kothari and R. C. Majumdar. In a series of papers in early thirties, they calculated the opacity of degenerate matter in the stellar cores and the physics of energy transport phenomena following rigorous quantum mechanical treatments.[55 56 57]

3. *Banaras Hindu University.* While Saha and his students worked in stellar atmospheres and interiors, another group led by V. V. Narlikar started work in cosmology at the Banaras Hindu University. V. V. Narlikar endeavoured for the creation of a group in cosmology. He was able to produce a few students who carried out his line of work. [23 60] His son J. V. Narlikar, as also his first student P. C. Vaidya made impacts in this field later.

Amateur Astronomy in Early 20th Century

The role of amateurs in astronomy has always been significant. While the efforts of Indian amateurs have not been on the same scale as some of those in western countries, special mention must, however, be made of a few individuals, viz. Fathers Johann Grueber and Albert O'orville who were contemporaries of Father Richaud.[61] Since then there have been several efforts of amateurs at observing solar eclipses and events like the transit of Venus. We have already mentioned that Nawab Zafar Jung's interest in astronomy led him to establish the Nizamiah Observatory. At Vizagapatnam. A. V. Narsinga Rao with a 6-inch telescope made observations of the transit of Venus and Mercury and also observed many bright comets. The work of amateurs in the study of variable stars is considerable.[9] The pioneer in the study of variable stars was R. G. Chandra from Jessore who from 1919 until the late forties was a regular contributor to AAVSO (American Association of Variable Star Observer). Chandra's observations were made with a 3-inch refractor owned by him. He was later loaned a splendid 6-inch Clark refractor by the AAVSO to extend his observations to fainter stars. [62 63]

In the field of meteors, M. A. R. Khan of Hyderabad made numerous observations. Khan's observations were regularly sent to the American Meteor Society and for many years he was the outstanding observer. Special mention must be made of the amateur association which sprung up during the period to foster the study of astronomy. Way back in 1910 a few gentlemen in Calcutta decided to form a society

which was called the Astronomical Society of India. The idea arose from the interest generated during the appearance of the Halley's comet. It attracted a very large membership and in a few months of its starting it had 117 members. The association was divided into various sections and a person was made the director of each section. The Association held lectures and symposia and brought out the *Journal of the Astronomical Society of India*. Ten volumes of this journal seem to have been published, and well-known scientists like C. V. Raman, M. N. Saha, J. Evershed, T. Royds, R. J. Pocock, A. B. Chatwood, and T. P. Bhaskaran have contributed to this journal. C. V. Raman published as many as 6 papers in this journal. It also had interesting articles on grinding of mirrors and how to make one's own telescopes. The Society possessed a 8½-inch reflecting telescope which was housed in the 'Imperial Secretariat Buildings' and was available for use by the members of the society.[9]

H. P. Waran of Madras is credited to have made the largest aperture paraboloid before 1947. He used a grinding machine fabricated by himself for the purpose. The mirror of 24-inch aperture was the primary of a reflecting telescope that could not be completed due to paucity of funds.[9] Another notable effort in amateur telescope making was by S. K. Dhar and Brothers of Hooghly. They started the manufacture of mirrors for reflecting telescopes as an amateur activity and later formed a professional company.[64]

POST-INDEPENDENCE ASTRONOMY

An important landmark in the history of Indian astronomy in the twentieth century is the setting up of a committee under the chairmanship of Prof. M. N. Saha. The committee was constituted in 1945 to draw up plans for the development of astronomical research and teaching in India at the existing observatories and and universities. The recommendations of this committee gave a tremendous boost to astronomical activity. The main recommendations made by this committee are the following :—

1. The establishment of an astronomical observatory with a telescope of large aperture.
2. The extension of facilities of a coronagraph, solar tower telescope, large aperture Schmidt telescope and a laboratory for solar-terrestrial studies.
3. Establishment of a Naval Observatory and nautical almanac section.
4. The need for post-graduate teaching of astronomy and astrophysics at the universities where establishment of observatories with 15-inch aperture telescope was recommended.[65] Most of the committee's recommendations, specially in so far as Kodaikanal Observatory is concerned, have been implemented in subsequent years.

This was also the period in which astronomical research in the other regions of electromagnetic spectrum started to make a beginning. Some important experiments were Karl Jansky's experiments in radio astronomy and the work of Reber confirming

Jansky's early work, theoretical investigation by H. C. Van de Hulst in 1944 predicting the 21-cm radiation and its confirmation 6 years later, the first rocket with scientific pay-load which went up in 1946, and the launching of first artificial satellite in 1957.[65] Several institutions in India encouraged young scientists to pursue astronomy. Saha had created a fund for building a Radio Telescope in India in 1950; the first Radio Telescope was built in 1952 at Kodaikanal to study the Sun. Many groups of scientists all over India intensified their studies of cosmic rays; the Tata Institute of Fundamental Research (TIFR) group organized balloon-borne experiments reaching high up in the atmosphere. This group in course of time developed instrumentation for x-ray and for infrared studies. In the familiar optical band, observatories at Naini Tal, Rangapur and Kavalur were established with modern equipment. In keeping with the general overall expansion on scientific activities, several groups of theoretical astrophysicists were formed in various universities and institutes. A short description of these developments is given in the next few sections.

Optical Astronomy

Observational work in optical astronomy in India today is mainly being carried out at the Indian Institute of Astrophysics in Bangalore, Centre for Advanced Study in Astronomy at Osmania University, Hyderabad, Uttar Pradesh State Observatory at Naini Tal, and Physical Research Laboratory in Ahmedabad; some limited observational work is also being done in a few universities.

Indian Institute of Astrophysics

The old Madras and Kodaikanal Observatory was converted into an autonomous research institute called the Indian Institute of Astrophysics in 1971.[66] Optical observations at the Indian Institute of Astrophysics are being done from the two observatories; one at Kodaikanal and the other at Kavalur which was started in 1967.

Solar Physics. The observatory at Kodaikanal is concentrating on the studies of the Sun. The old instruments by which considerable scientific progress was achieved have been supplemented by modern equipment. A. K. Das, who was Director of this Observatory (1946-1959) (keeping in line with Saha committee's recommendations) equipped the observatory with several new instruments: (i) The new instrumentation at the solar tower consisting of a large solar telescope combined with a powerful spectrograph of exceptionally high dispersion and resolving power; the solar telescope consists of a coelostat with three telescope object glasses of 37.5 cm and 20 cm apertures; it was constructed by the famous Grubb Parsons of England; (ii) a coronagraph built in Paris by the associates of Lyot; this is of 20 cm aperture; (iii) a monochromatic heliograph with Lyot filter; this filter was also purchased from France but the design and construction of mechanical parts for the heliograph were done in the observatory.[67 68]

The large solar telescope has now a photoelectric magnetograph which makes fine measurements of magnetic and velocity fields on the sun possible. The tower

telescope has been used for high resolution studies of the solar chromosphere, of the Evershed effect in sunspots and the five-minute oscillations observed on the solar surface. It has also been utilized for the study of evolution of active regions and some of the characteristics of chromosphere over such areas. A very significant contribution with its aid has been the idenufication that bright fine mottling in the chromosphere is responsible for the relationship found by Wilson and Bappu between K emission line-widths and absolute magnitudes of stars.[69 70]

Solar Eclipse Studies. During the period 1950-1983, the Indian Institute of Astrophysics participated in the observations of six solar eclipses. An expedition headed by A. K. Das went to Iraq in 1952 and to Ceylon in 1955. Unfortunately both the expeditions were frustrated by bad weather at the time of the eclipse. M. K. V. Bappu led the next three expeditions to Maine, USA in 1963, Miahautlan, Mexico in 1970 and in India in 1980. In 1983 a 5 member team led by K. R. Sivaraman went to Tanjung Kodok in Indonesia.[71 72 73 74]

Solar corona research formed the main aspect of these eclipses. Among the important observations during the expeditions, the high resolution coronal photographs with 6 m focus horizontal camera and a fine coronal spectrogram deserve special mention. During the 1970 eclipse, Bappu, Bhattacharyya and Sivaraman identified on the coronal spectrogram emission lines of Balmer series, the helium D_3 line, and H and K lines of ionized calcium which indicated the presence of relatively cooler regions in the corona.[71] These findings were confirmed from the results obtained by the 1983 eclipse team.[74]

During the eclipse of February 1980 when the path of totality crossed the Indian peninsula, an elaborate observational set up was established. Two camps were set up, one at Hosur about 49 km south of Hubli, and another at Jawalgere 50 km west of Raichur. The camp at Hosur housed the long focus camera for the photography of corona, the polarigraph and the coronal spectrograph. The high dispersion multi-slit coronal spectrograph, the spectrograph for rapid sequence photography of the neutral potassium line close to the solar limb, a Paschen Runge monochromator for limb darkening measurements and a telescope with the 0.5A H-alpha filter were set up at Jawalgere camp. The equipments consisted of modern photo-electric image intensifiers, narrow-band polarizing filters and several pieces of sophisticated electronic equipment. White light photographs of excellent quality showed the presence of coronal transients. The multi-slit spectra helped in mapping the turbulent velocities in the corona.

Studies of the solar system, stars and galaxies

Optical observations of the stars and solar system objects have been conducted from both the observatories at Kodaikanal and Kavalur. Until 1960, the main emphasis was in solar physics. But after Bappu became the Director, emphasis was also placed on stellar physics. Kodaikanal had a 20-inch Grubb reflector originally belonging to Maharaja Takhtasingji Observatory, Poona, and also an eight-inch

refractor; these were equipped by Bappu with a photometer and a spectrograph. The 20-inch reflector, popularly known as the 'Bhavnagar Telescope' was originally purchased for the Maharaja Takhtasingji Observatory at Poona where K. D. Naegamvala was the Director. After his passing away, the Observatory was dismantled and in 1912 the instruments were transferred to Kodaikanal Observatory. It was the largest telescope in the country at that time, and served as the principal instrument for stellar observations for a long time. Kodaikanal Observatory was invited by the International Mars Committee to join the world-wide photographic and visual patrol in 1954, Three papers on Mars were published using this telescope.[71] [77] Other important studies made with this telescope were spectrographic study of Wolf-Rayet stars and Comet Ikeya-Seki. Among other objects, the binary star gamma Velorum, Nova Delphini and several stars of Scorpio Centaurus association were extensively studied. This telescope was later shifted to Kavalur and is now earmarked for Leh where special observations in connection with establishment of a National Astronomical Centre are being planned.

Kavalur in Tamil Nadu was chosen as the suitable site for stellar observations after an extensive site survey. Regular observations started in 1968 with a small telescope, and the big boost for the programmes came with the acquisition of 102-cm reflector in 1972. Several auxiliary instruments have been subsequently added including a vertical Coude spectrograph and an on line computer system for photometric and spectro-photometric studies. A computer-controlled spectrum scanner was designed and fabricated in the Institute's laboratories. The 40-inch telescope was the first to provide some degree of competitive research capability and in a few years of functioning had some striking achievements to its credit.[78] Within a fortnight of its installation, observations made with it during a rare occultation event showed the presence of an atmosphere on Ganymede, a satellite of Jupiter. Prior to this discovery, Titan, the largest satellite of Saturn was the only satellite in the entire solar system known to have possessed an atmosphere of its own; Ganymede thus became the second satellite with visible evidence of an atmosphere.[79] A new technique using microspectra was developed with 102-cm reflector for the detection of quasi-stellar objects. The spectroscopic observations obtained with the Coude spectrograph showed evidence of active regions similar to those on the solar surface on the bright southern star Canopus. The discovery of ring system around Uranus[80] and the outer ring system of Saturn is among the important achievements made with this telescope.

Besides this telescope, the Institute has produced a few smaller telescopes of its own design and commissioned them for observational use. A 38-cm reflector was made in the Kodaikanal worshop in 1967 and was the first telescope to be used at Kavalur Observatory. A 75-cm reflector was fabricated in the Institute's laboratories and is now installed at Kavalur. The Institute has several other telescopes under fabrication including a 60-cm Schmidt for sky survey work. The task of building a large 234 cm optical telescope has been undertaken by the team of scientists and engineers at the Institute. The need for a large telescope for studying fainter objects was felt even during pre-independence days. Saha recommended one in his Committee report and Das in his booklet *Modernisation of the Astrophysical Observatory*

has mentioned that the plans to acquire two large telescopes for Kodaikanal, a 100-inch reflector and a 46/34-inch Schmidt Cassegrain telescope, had already been made but due to financial difficulties, it was not possible to get them. It was only during Bappu's period that the plan was sanctioned and the task of building up a large telescope was undertaken. The 2.34 m telescope has been designed and fabricated indigeneously. The mirror has been ground, polished and figured to a very high degree of precision. The mechanical parts have been designed by Indian engineers under the guidance of the Institute scientists. When installed, this will be the largest optical telescope in Asia.[78]

Studies of stellar atmospheres and their compositions using high dispersion spectrograms, lunar occultations of stars, structure and distribution of globular clusters and planetary nebulae, distribution of young stars in galactic spiral arms, close binaries, study of Novae and variable stars are some of the programmes currently undertaken here. In the area of extragalactic astronomy the structure and spectra of the nuclei of galaxies and the structure of nearby galaxies are carried out. Investigations on comets and asteroids also form part of the activity being pursued.

Centre for Advanced Study in Astronomy, Osmania University

The Nizamiah Observatory (which later became part of the Osmania University) had a 15-inch refractor to start with. This was mainly used for variable star observations and occultation programmes. In addition to this there was an 8-inch astrograph with a 10-inch finder telescope. It also had a spectrohelioscope supplied by Messers Howell and Sherburne, Pasadena and observations with this instrument were seriously taken up in 1945. The Observatory participated in the solar and seismological observation programmes during the International Geophysical observation programmes during the International Geophysical Year (1957-1958) and the observation of the Sun during the International Quiet Sun Year (1964-65). Plans to modernize the observatory were taken up with the financial assistance of the University Grants Commission. A number of other measuring instruments and machinary were also acquired. In 1959 a separate teaching department of astronomy was started at the University. Along with K. D. Abhyankar, V. R. Venugopal moved to Osmania and started the first teaching programmes. A. K. Das served as the Director for a short while on his retirement from Kodaikanal. His term ended abruptly due to his sudden death in 1961. R. V. Karandikar who was chosen to lead the team could not join until June 1963. In the intermediate period, K. D. Abhyankar served as in-charge Director. Karandikar, after joining as Director, completed the installation of the 48-inch telescope. A hillock near two villages Japal and Rangapur about 55 km from Hyderabad was chosen for installing the 48-inch telescope and in 1964 UGC recognized the astronomy department and the observatory facilities at the Nizamiah and Japal-Rangapur as a Centre for Advanced Study in Astronomy (CASA). The 48-inch telescope was commissioned in 1968 December. The new facility is being used for photoelectric and spectroscopic observations of variable stars, mainly the eclipsing and spectroscopic binaries. A photoelectric photometer was built in the observatory workshop and has

been used with the 15-inch refractor for photoelectric observations.[47] Abhyankar who was a student of Struve encouraged research of binary stars at the centre. Now Hyderabad is one of the leading centres for investigating binary stars.

The path of totality of solar eclipse of 1980 February 16, crossed over the observatory at Japal-Rangapur. The Nizamiah astrograph was shifted there to conduct a special observation of gravitational deflection of light. Polarization studies of solar corona in red and blue light for determining the electron densities were made using the 4½-inch telescope with polariods, mounted on the 48-inch telescope.

Uttar Pradesh State Observatory (UPSO), Naini Tal

This was one of the observatories that came up in the post-Independence period. In 1947 the Government of Uttar Pradesh decided to set up an astronomical observatory and in 1952 an expert committee was formed with A. N. Singh, as the convenor. The Astronomical Observatory was located at Varanasi and started functioning by 1954. A Cooke, gravity-driven, 25-cm refractor, a set of Rhode and Schwarz quartz clocks and a few other accessories were purchased and formed the original observational equipment. A. N. Singh was entrusted with the task of setting up of the observatory. The observatory commenced visual observations of comets, asteroids and double stars with the help of the 25 cm refractor. After the death of Singh, M. K. V. Bappu, a young astronomer was appointed as the Chief Astronomer. He took active interest in the growth of the observatory during the period 1954-1960. It is due to his initiative and vision that the development plans of the observatory were put on a sound base. The role of Dr. Sampurnanand, the Chief Minister of U.P. in connection with the modernization of this Observatory is very important. One of the first tasks of Bappu was to locate a place to install the proposed telescope. After much site testing the Manora Peak in Naini Tal was found suitable. The observatory was soon shifted to Naini Tal and regular stellar observations commenced. After Bappu left for Kondaikanal in 1960, Sinvhal succeeded him as Director and carried out the development projects. The observatory has a 15 cm reflector and another 38 cm reflector telescope. The observatory also has a 52 cm reflector with folded Cassegrain and Coude foci acquired essentially for solar work. The chief facility at this observatory at present is the one-metre Zeiss reflector named as Sampurnanand telescope which is a duplicate of the instrument available at Kavalur. The observatory has an optical workshop which can polish and grind mirrors upto 75 cm diameter. The observatory has undertaken several observational programmes like determination of orbital elements and basic parameters of eclipsing binary systems through UBV photometry, determination of temperature and radius variations from energy distribution curves of classical Cepheids, analysis of UBV light curves of RR Lyrae stars, determination of light and colour curves of Delta Scuti stars. Study of latetype stars and photometry of galactic clusters are also being done. In solar system studies, photometric medium-band observations of comets Bennet, Kohoutek, West and Bradfield were undertaken. Naini Tal has also undertaken several occultation programmes. It had observed the occultation of SAO 158687 by Uranus in 1977 and identified the ring system around Uranus thus

confirming the observations made at IIA. The observatory has prepared a plan for setting up a large telescope of 4 m aperture at a suitable site in the Himalaya lower range near Naini Tal.

In solar physics, observational and theoretical studies of dissociation equilibrium and profiles of diatomic and triatomic molecular lines based on the various sunspot, photospheric and average facula models are in progress. Study of magnetohydrostatic and magnetohydrodynamic models of prominences have been undertaken. The observatory, while still at Varanasi sent an expedition to Ceylon to observe the total solar eclipse of 20 June 1955. The objective was to carryout the polarimetry of solar corona with the help of photographic coronal polarimeter. But the expedition was unsuccessful due to bad weather. The observatory also participated in the observations of the solar eclipse of February 16, 1980 and carried out a programme on coronal photometry, and photography of the 'flash' and coronal spectra.[81]

Udaipur Solar Observatory

For optical studies of the Sun, a special solar observatory has been set up in Udaipur, Rajasthan. It has a 12-ft solar telescope for high spatial and time resolution studies of solar events.

In 1972 an organization called Vedhashala was set up at Ahmedabad with the aim of doing astronomical research. With their assistance, a solar observatory in the midst of a lake in Udaipur was established for high resolution studies of solar features. Later, however, the organization withdrew its support and the observatory was taken over by the Government of India. At present this functions under the administrative control of the Physical Research Laboratory, Ahmedabad and carries out observations of the Sun. The 12 ft Spar telescope is located in a small island in the midst of Fateh Sagar Lake. Owing to the presence of large body of water, seeing conditions are excellent over long periods during the day. The observatory is mainly involved in high spatial and time resolution chromospheric and photospheric studies of flares and other transitory phenomena.[82]

Positional Astronomy Centre, Calcutta

This centre under the administrative control of the India Meteorological Department, which has been entrusted with the publication of the astronomical almanac, has recently acquired a pair of celestron telescopes (36 cm and 26 cm). The telescopes are intended for visual observations of celestial objects for positional astronomical studies.

Physical Research Laboratory

A telescope of 1.2 m aperture mainly intended for studies in the infrared is currently under fabrication and will be installed at Gurushikhar in Mt. Abu; the telescope is expected to become operational in 1985. Though originally intended

for dedicated work in IR astronomy, PRL is planning to use it for optical astronomy as well. A high resolution pressure scanned Fabry-Perot spectrometer has been fabricated by scientists of this Laboratory.[83] At present the scientists have been utilizing the telescopes at Naini Tal and Kavalur for their observations. The laboratory has also constructed a Fourier Transform Spectrometer for high resolution spectroscopy of celestial objects. In collaboration with IIA, PRL has been observing with this instrument several peculiar planetary nebulae to map their velocity fields. PRL has also completed a polarimeter to be operated with 1 m telescope at Kavalur. Polarimetric studies of carbon-rich Mira type long period variables to understand the formation and distribution of circumstellar dust is also in their programme.

Tata Institute of Fundamental Research, Bombay

Optical observational programmes in TIFR were started recently. This centre has been utilizing the telescopes at Japal-Rangapur and Kavalur for certain specialized programmes. In collaboration with the Osmania University they are making optical observations of X-ray sources and some suspected Rs CVn systems, and in collaboration with IIA, optical observations of some infrared sources.

Other Institutions

A solar telescope fed by a coelostat has been in operation at Nehru Centre, Bombay for the past few years. No regular scientific programmes have, however, been undertaken. Punjabi University, Patiala has acquired a 60 cm reflecting telescope. The telescope, however, is still to be installed and brought into regular use.[84] Two colleges in Calcutta, St. Xavier's and Presidency and also the Delhi University have a telescope each on their respective campuses. Although extensively used at one time, the instruments are not in regular use now.

An unaccounted number of small telescopes exist in several educational institutions in the country. Some of the instruments are quite old and have been used for serious observations at some epochs of their existence. Several universities have acquired optical telescopes and these are mainly in charge of the university departments of physics or mathematics. These are almost exclusively used for instructional purposes and not used in any observational programme. In some universities where astronomy is offered as a special subject, some basic observational experiments using these telescopes are included in their curriculum.

Radio Astronomy

Radio astronomical research in India is relatively new. In spite of this late start, there have been significant results in this field. First efforts to start radio astronomy in India were made by Saha in the early 1950's. M. K. Das Gupta from the Manchester group who joined the Institute of Radio Physics and Electronics was called upon to take up a major role in this venture. Saha's premature death, however,

caused a setback in the scheme. After his death some of his students and admirers decided to set up a Radio Astronomy Institute in the memory of Saha, and raised a sum of Rs. 5,00,000/- from the public for this purpose. But due to lack of determined efforts in following it up, the project did not see the light of the day.[85] Several other institutes have subsequently ventured into this field as described below.

Indian Institute of Astrophysics

At the Kodaikanal observatory, radio astronomy had its beginning in the year 1952 under A. K. Das when continuous recording of solar radio noise flux was commenced using a 100 MHz interferometer with twin Yagi type antennas. This telescope was designed and built locally using the observatory's own facilities.[86] With available instruments, scintillation observations of Cygnus A and Cassiopeia A were made. In the year 1962 a Kodaikanal-Yale project of recordings the radio radiation of Jupiter at a frequency of 22.2 MHz was also started. Later a 3000 MHz radiometer was in regular operation for solar patrol on a tracking 2 metre diameter paraboloid.[87]

In the 70's a collaborative project between Indian Institute of Astrophysics and Raman Research Institute, Bangalore was commenced. A Decameter Wave Radio Telescope was jointly set up by the two Institutes at Gauribidanur, 100 km north of Bangalore, which became operational in 1979. At present it is one of the largest telescopes of this type in the world. It consists of two long antenna arrays, one oriented in E-W and the other in N-S direction, of lengths 1.5 km and 0.8 km respectively. Operating at a wavelength of 10 metres the telescope can resolve objects whose angular separation is about 25 minutes of arc in the sky.[88] One of the aims of the telescope was to survey and catalogue the galactic HII regions which would appear as absorption region against the background non-thermal continuum. It is being used to study radio emission from various types of celestial objects such as the Sun, the planets Jupiter and Saturn as well as extended radio sources in our galaxy and external galaxies. Some of the important studies made using the Decameter Wave Radio Telescope include (1) the detection of continuum radiation from the outer solar corona during quiet periods, and studies of solar absorption and emission bursts, (2) mapping of electron temperature distribution across the ionized hydrogen region, Rosette Nebula, and (3) detection of diffuse radio emission from the Coma cluster of galaxies. As a beginning in stellar radio astronomy in a guest observers programme, VLA has been used by IIA and TIFR scientists to study ejected hydrogen envelopes from extreme hydrogen deficient stars.

Tata Institute of Fundamental Research

Another group of scientists actively engaged in radio astronomy is at the Tata Institute of Fundamental Research. Radio astronomy at this Institute had its beginning during the middle sixties when H. J. Bhabha extended the facilities of TIFR to construct a radio telescope at Ooty. Bhabha pursuaded young radio astronomers wroking abroad to come home and start work in this field, G. Swarup, M. R. Kundu

and T. K. Menon returned from various institutions in the US and started this venture. As a first step, it was decided to set up a high resolution interferometer at Kalyan near Bombay for studying the Sun. The radio interferometer was designed for making solar observations at 610 MHz with a resolution of 2.3 arcmin in East-West and 5.2 arcmin in North-South direction. It consisted of 32 parabolic dishes of 1.8 m diameter located over a base-line of about 630 m in East-West and 256 m in North-South directions. The instrument was first used to make a 2-dimensional map of the Quiet Sun at 610 MHz. It was used for the study of the solar corona and solar bursts. However, as a long-term project it was decided to put up a low cost yet a large and powerful telescope of a new design. A search was made for a suitable location for a large steerable radio telescope and Ooty in South India was chosen as the appropriate place. The Ooty telescope was successfully completed and was made operational during 1970. The telescope is a 530 m long and 30 m wide cylindrical paraboloid placed on a mountain slope aligned with the earth's rotation axis and operated at 326.5 MHz. The initial primary programme was the measurement of positions and extent of radio sources by lunar occultation method.[89] The Ooty Radio Telescope is a spectacular success and has put India in the forefront of radio astronomical research in the world. Some of its major contributions are the determination of the positions and structures of thousands of radio sources with arcsecond resolution which helped studies in observational cosmology in a major way. Discovery of a few new pulsars was achieved through pulsar search programme undertaken by the Observatory. Valuable information on the distribution of electron densities in the galaxy has been secured using the interplanetary scintillation technique for radio observations of radio sources. Several attempts have been made to detect stellar flares. Recently several astronomers have used the VLA for the study of supernova remnants and hydrogen line emission.

As a next step in their programme a more refined equipment was taken up. Ooty Synthesis Radio Telescope (OSRT) consisting of Ooty radio telescope and 6 smaller parabolic cylinders of 112 m $\times$ 7.5 m size spread along a baseline of 4 km have already been installed. The OSRT will provide a new tool to study radio sources with high sensitivity and spatial resolution at meter wavelengths. Using OSRT, mapping of some interesting radio galaxies is already in progress.[90]

Physical Research Laboratory

PRL had started with solar radio observations in late sixties and installed a radio spectrograph for studies of solar bursts. Their interest, however, later changed to interplanetary scintillations (IPS). At the present moment they are setting up a three-station array operating at 103 MHz for these studies. The three stations are located at Thaltej (near Ahmedabad), Rajkot, and Surat. Regular IPS observations of radio sources such as 3C 273 and 3C 298 have been made at varying angles from the Sun and the transition from a weak scattering to a strong scattering region in the interplanetary medium has been identified. Angular sizes of these quasars have also been obtained. The laboratory has also plans to operate the array in VLBI-mode for high resolution (3 arcsec) studies of galactic and extragalactic radio sources.[84]

Raman Research Institute, Bangalore

The Raman Research Institute started its programmes in astronomy after V. Radhakrishnan took over as Director, in 1972. The Institute entered into a collaborative project with the IIA on the construction of the large low-frequency array at Gauribidanur. As already mentioned the telescope is now being used to study radio emission from various types of objects such as the Sun, Jupiter, our galaxy and external galaxies. The scientists of this Institute have also started observational programmes with the Ooty Radio Telescope. Among the programmes being carried out or completed using the Ooty telescope are a very sensitive search for deuterium in the interstellar medium, the accurate determination of positions of pulsars, and a major survey of recombination lines in the galactic plane. The last mentioned programme has produced significant result in the understanding of conditions in the more diffuse part of the interstellar medium in our galaxy. The Institute is currently engaged in constructing a millimetre wave telescope of 10.4 m diameter. Very sensitive receivers to operate in the millimetre wavelength range are being built in the Institute's laboratories.[91]

Osmania University

Although the Centre of Advanced Study in Astronomy possessed good optical set up, their facilities for observations in other bands of electromagnetic spectrum were non-existent until a few years ago. For observations during the total solar eclipse of February 16, 1980 the centre entered into a collaborative plan with PRL and S. A. C. Ahmedabad for observing the Sun in cm wavelengths. Such a set up with a 10 ft steerable dish was installed at Japal-Rangapur Observatory in early 1980 by means of which high resolution microwave brightness temperature measurements were made during the eclipse. The equipment has been retained at site where regular observation of solar flux at 10 MHz are now being carried out.[92]

X-RAY ASTRONOMY

Presently, mainly two institutions in India are engaged in research in X-ray astronomy. These are TIFR Bombay and ISRO Satellite Centre, Bangalore. Earlier, PRL also had a programme in this field but this is now transferred to ISSC. X-ray observations have been carried out mainly using rockets, balloons and satellites.

Rocket-borne astronomical observations have been made in the X-ray range of energy 0.1 to 20 keV. Transient X-ray sources such as Cen X-1, X-2 and X-4, binary sources like Sco X-1 and Cir R-1 supernova remnants and the diffuse X-ray background have been extensively studied in these experiments. Energy spectra of sources, temperatures, electron densities and sizes of the emitting regions have been deduced from these observations. Balloon-borne X-ray astronomical observations in the energy range of 20-200 keV have been carried out by the group for study of hard X-ray emission, from a number of X-ray objects like Her X-1 and Cyg X-1.

The first Indian satellites Āryabhaṭa and Bhāskara designed and fabricated by ISRO were to carry out X-ray experiments. Observations of the intensity fluctuations of a transient nature from Cyg X-1 during April 1975 were reported from the data obtained from the two satellites. Unfortunately the satellites did not operate long enough to provide significant results.

X-ray astronomy programme at TIFR started in 1975. They carried out a few balloon-borne experiments where the X-ray emission from Sco X-1 was detected. The group also collaborated with the University of Calgary, Canada and Astrophysics Laboratory, Frascati in two separate joint research programmes where several X-ray objects like Her X-1, Crab Nebula etc. were studied. Simultaneous optical observations during three balloon experiments were provided by ground-based telescopes at Kavalur and Japal-Rangapur Observatories. Presently, the balloon launching facility near Hyderabad is being used for experiments in high energy range. In a guest observers programme they have undertaken a number of interesting observational programme with the NASA satellites SAS-3 HEAO-1 and Einstein Observatory. These studies have led to the discovery of some new X-ray sources and a new pulsar.[84]

Cosmic Ray Research

Cosmic ray research in India began in 1938 with cloud chamber studies at the Palit Laboratory of the Calcutta University and in 1942 at Saha's house in Darjeeling. Ground-based cosmic rays studies by foreign scientific teams date back to 1926 when Arthur Compton of the University of Chicago collaborated with P. L. Bhatnagar and others from the University of Punjab (Lahore). With combined equipment, they camped on a lake in Kashmir at 17,000 ft for a week measuring the intensity of cosmic radiation at various depths (down to 250 feet). The difficult work was terminated by a blizzard in which the equipment was temporarily lost. In 1955 a five-year plan of development was proposed by Saha for research in cosmic rays. Work was to continue at 8000 ft in Darjeeling with two new stations, one at 7,200 ft at Jalapahar and the other at a point on the Darjeeling-Lhasa Road at 16,000 ft. The work, however, could not progress due to inactivity on the part of government and was abandoned after the death of Saha. Some experiments in cosmic ray research were conducted at the Bose Institute, Calcutta under D. M. Bose and Indian Statistical Institute under P. C. Mahalanobis.[85]

At Tata Institute of Fundamental Research, cosmic ray studies were conducted by carrying nuclear emulsion assemblies and electronic instruments to altitudes of 30-40 km in rubber balloons, and in large volume plastic balloons, in 1950's. Studies were also conducted in Mountain altitudes to study large extensive air showers produced by cosmic rays of energy greater than 10^{13} eV and in a deep underground site in Kolar Gold Fields to investigate the variations and intensity distribution of muons and neutrions. These researches opened up new avenues for the study of solar system. The technique of track revelation in grains found in meteorites and later in

Moon samples was developed and refined to the extent that they led to new discoveries.[89]

TIFR experiments are in progress to study the elemental and isotopic composition of cosmic rays at energies of hundreds of MeV and below using plastic detectors. A joint experiment by TIFR and PRL with a plastic detector assembly capable of giving time resolution with a moving film arrangement was selected by NASA in 1977 for inclusion in their space shuttle.

A variety of problems relating to the origin and source of cosmic rays, their acceleration, energetics and propagation in source regions and interstellar space have also been taken up at TIFR. In addition, studies of the role of cosmic rays in the large-scale dynamics of the galaxy, in relation to exotic objects such as supernova remnants and neutron stars and in problems of cosmological nature are being pursued.

At PRL ground-based cosmic ray detector were used to study temporal variation in their intensities. For these, results of great importance were obtained in fields such as periodic intensity variation, modulation of cosmic rays in the heliosphere, properties of the interplanetary medium, solar flare effects and solar wind effects. Also at PRL the novel techniques of track revelations in lunar and meteorite grains have given very valuable information on its pre-history, i.e. the intensity of cosmic tradition over millions of years. PRL also has a programme in cosmic ray astrophysics.

At the Panjab University, work has been carried out on the composition of cosmic rays using nuclear emulsion technique. Investigation in cosmic-ray astrophysics is also being carried out at the University of Calcutta, and some work in cosmic rays is being done in Gauhati University. Nuclear Research Laboratory at Gulmarg, Aligarh Muslim University and APS University at Rewa are engaged in solar modulation studies.[84]

Infrared Astronomy

Infrared astronomy in India is less than a decade old. Observational programmes are usually collaborative ventures between scientists of different research institutes. Groups at PRL and TIFR are carrying out ground-based IR observations in windows in near IR (1-3 micron) using PbS and InSb detector systems since 1978 and 1980 respectively. IR observations are presently being carried out using the 1 m telescope of Kavalur and Naini Tal observatories and 1.2 m telescope at Japal-Rangapur Observatory. Main programmes by the PRL scientists are the photometric measurements of Be stars, bright stars with special characteristics, open clusters, dark clouds and circumstellar envelopes. In another programme, in collaboration with IIA, observations of characteristics of RCrB stars have been obtained to study the variations of IR flux and the distribution and production of circumstellar dust. PRL and TIFR groups, using the 1-m telescope of IIA detected infrared bursts from the globular cluster LillerI.[92]

Balloon borne MARK II infrared telescope fabricated by the joint efforts of TIFR and Vikram Sarabhai Space Centre, Trivandrum was flight tested in late 1980. The instrument weighing 900 kg and containing most sophisticated components was successfully launched from Hyderabad balloon facility. The instrument performed satisfactorily, but unfortunately since the flight termination control failed the entire instrument was lost. However, the data obtained in December 1980 flight contained considerable scientific information. Infrared signals in 70-130 micron band were observed from Jupiter, Saturn and Orion A. A new system incorporating a mirror of 1 m diameter and an improved star tracker has since been built, but not yet tested in flight.[84]

In a collaborative programme with Meudon Observatory, PRL has participated in far-infrared observations aboard an aircraft. The source observed was Large Magellanic Cloud (LMC). In another collaborative programme with the University of Arizona, photometric observations in the infrared were made of SS 433, BL Lac, and the galactic centre, in addition to the few T Tauri stars from the telescopes at Kitt Peak Observatory, USA. PRL scientists have fabricated a high-resolution Fourier transform spectrometer and spectropolarimeter for studies of the near-infrared. IIA, jointly with the Royal Observatory, Edinburgh has taken up infrared studies of RCrB stars by using the special instrumentation on IRAS (Infrared Astronomical Satellite).[92,93]

A 1.2 m telescope dedicated for IR work at Mt. Abu is presently under fabrication jointly by PRL, IIA and SHAR; this and the 2.34 m telescope now nearing completion will be used for infrared experiments in very near future.

Gamma Ray Astronomy

Gamma-ray astronomy in India is still in its infancy. There have been some collaborative programmes between India and the Soviet Union. During the first phase of the programme, the balloon-borne Natalya 1 gamma-ray telescope was successfully launched. A study of the galactic anticentre region in 6-150 MeV energy region was made. Now the second phase of the programme which involves a joint gamma-ray astronomy experiment on a Soviet satellite is underway.

TIFR has been observing very high energy gamma-rays through Cerenkov light flashes in the atmosphere collected by a series of photon detectors arranged at an observing station at Ooty. A special microprocessor-based photon detector system have been built to accurately measure the time of arrival and shape of optical pulses. The Crab is being monitored with 1 m telescope at Kavalur. A joint TIFR-IIA experiment to study gamma-ray bursts and their relation to optical pulses from Crab Pulsar was undertaken in November 1983. Another experiment for detection of celestial gamma-ray sources has been set up at Gulmarg, Kashmir, by the Nuclear Research Laboratory of the BARC. The main interest here is low energy gamma-ray bursts from supernovae and mini-black-hole explosions.

UV Astronomy

Work on UV astronomy requires the facility of space-crafts or balloons. UV astronomy is being carried out by IIA and TIFR through the guest observers programme of International Ultraviolet Explorer satellite. At present, there is no facility in the country to pursue the study of this important spectral region. Development of such a facility should be attempted soon. The main programmes that are being proposed at IUE are the chromospheric and circumstellar properties of hydrogen-deficient stars and cooler binary stars with hot companions for a study of the nature of the companions.[92]

Theoretical Astrophysics

Research in theoretical astrophysics has been extensively carried out by groups both in the national institutions and several universities. At the Indian Institute of Astrophysics, theoretical research in astrophysics covered many areas. It may be broadly divided into (1) physics of the atmosphere of the Sun and stars, (2) physics of the interstellar medium, (3) extra-galactic objects and high-energy astrophysics, and (4) plasma astrophysics. Various topics in solar and stellar atmospheres consist of radiative transfer in spherical media and fine structures in the solar atmospheres. Studies in interstellar medium comprise of interstellar clouds, grains and ionized hydrogen regions. Aspects of stellar evolution including formation of novae, supernovae, planetary nebulae are actively pursued. Studies of extragalactic objects and high energy phenomena include supernovae and black holes along with stellar content of galaxies, active galactic nuclei, quasi-stellar objects and pulsars. Topics in plasma astrophysics cover MHD processes on the Sun and supernova remnants and radio bursts from the sun.

There is also a large group in TIFR working in theoretical astrophysics. The activities started in 1966 and spread over a number of topics in theoretical astrophysics including atmospheres of cool stars, convection zones in stars, models of pulsars and the state of matter at high density. With the discovery of pulsars, theoretical models were built for explaining the extreme regularity of pulsar periods and to explain the emission mechanism. The equation of state of cold matter has been studied by a number of workers to construct neutron star models. The evolution processes leading to the formation of collapsed objects were studied; the physical properties of white dwarfs, neutron stars and black holes were examined with special reference to their role in the context of pulsars and cosmic X-ray sources. Work is also being done in areas like molecules in comets, planetary physics, models of reflection nebulae in UV, and vertical flow in solar and stellar atmospheres. Different aspects of cosmology including nonstandard models, neutrinos in the universe, and gravitational lensing are being studied.

At the Raman Research Institute, active research has been pursued on various aspects of pulsars. Models have also been proposed for recently discovered milli-second pulsars. Supernova explosions, their mechanism, frequency and

consequent relation to pulsar birthrates have been topics of investigations.[91] Studies of interstellar molecular clouds is picking momentum.

The theoretical group of the Osmania University is carrying out research in topics such as dynamics of galaxies, radiative transfer in stellar and planetary atmospheres and positional astronomy. In Naini Tal, theoretical studies concerning the formation of molecular lines in Sun is actively pursued.

At the PRL investigations are being carried on in plasma astrophysics in topics relating to the structure and stability of accretion disks around compact objects and the dynamics of disk galaxies. Emission mechanisms and radiative transfer problems particularly with respect to high energy sources are being carried out.[93]

Research in observational and theoretical astrophysics has also been in progress in several universities. A short list of these centres is given in Table 1.

At Roorkee theoretical studies of the problems of stellar pulsations are pursued. At the Gauhati University areas like nuclear reactions in astrophysics, fission processes in astrophysics, nucleosynthesis and abundance distribution of elements, X-ray bursts, neutron star phenomena, plasma astrophysics have been studied. At Ravi Shankar University principal efforts are on cosmological interpretation of high redshift objects and theoretical investigation of the chemical abundance in extragalactic objects with particular references to QSOs, active nuclei of galactic and physical processes in extragalactic objects. At Burdwan University topics like properties of QSOs, compact objects and the formation of black holes are being studied. A brief mention of other topics of interest are shown in the Table. 1. Besides these groups, there are a large number of individual scientists in other universities who carry out investigations in various topics of theoretical astrophysics, often single handed. Efforts to extend help to these scientists by way of consultations, participation in symposia and in publications form a major part of activities of the Astronomical Society of India.

ASTRONOMY IN INDIA IN THE 20TH CENTURY

Table 1

List of Universities and Institutions with their Major Areas of Research

1. Aligarh Muslim University	Solar Physics, Cosmic Ray studies
2. Amaravati College of Engineering	Solar Physics
3. APS University, REWA	Solar Physics, Cosmic Ray studies
4. Banaras Hindu University	Solar System Research
5. Burdwan University	General relativity, Gravitation, Cosmology, Astrophysics
6. Calcutta University	Plasma Astrophysics, Cosmic Rays Research, Theoretical Astrophysics

7. Delhi University	Solar System Research, Plasma Astrophysics, Cosmology
8. Gauhati University	Theoretical Astrophysics, Cosmology, General Relativity
9. Gorakhpur University	Astrophysics and Cosmology
10. Gujarat University	Cosmic ray Research, UV, X-ray and gamma ray astronomy
11. Indian Association for the Cultivation of Science	Theoretical Astrophysics
12. Indian Institute of Astrophysics, Bangalore	Solar Physics, Stellar Physics, Interstellar medium, Extragalactic Astronomy, High Energy Astrophysics, Solar Terrestrial Relations
13. Indian Institute of Science, Bangalore	Cosmic Ray Studies
14. Indian Institute of Technology, Kanpur	Solar Physics
15. Indian Institute of Technology, Kharagpur	Solar Physics, Theoretical Astrophysics
16. Jodhpur University	Astrophysics and Cosmology
17. Kumaun University	Astrophysics and Cosmology
18. Meerut College	Solar Physics
19. Nagpur University	Astrophysics and Cosmology
20. Nehru Planetarium	Solar System Studies
21. National Physical Laboratory	Solar System Studies
22. North Bengal University	Cosmic Ray Research
23. Nuclear Research Laboratory	Solar Physics, Cosmic Rays
24. Osmania University	Solar Physics, Theoretical Astrophysics, Binary star research
25. Panjab University	Theoretical Astrophysics, Cosmic Ray Studies
26. Physical Research Laboratory, Ahmedabad	Solar System Research, Radio Astronomy, Infrared Astronomy Optical Astronomy, Cosmic Ray Studies, Plasma Astrophysics
27. Poona University	Theoretical Astrophysics
28. Punjabi University	Stellar Physics
29. Raman Research Institute	Theoretical Astrophysics, Radio Astronomy, Millimeter Wave Astronomy
30. Ravi Shankar University	High Energy Astrophysics
31. Roorkee University	Theoretical Astrophysics
32. Tata Institute of Fundamental Research	Solar System Research, Radio Astronomy, Infrared Astronomy, Cosmic Ray Studies, Theoretical Astrophysics
33. Udaipur Solar Observatory	Solar Physics
34. Uttar Pradesh State Observatory	Solar Physics, Optical Astronomy, Theoretical Astrophysics

As mentioned in an earlier section, N. R. Sen in Calcutta University and V. V. Narlikar in Banaras Hindu University may be considered as pioneers of research in general ralativity in India. In the Calcutta region some interesting work came from individual research workers, e.g. B. Datta's 'solution of gravitational collapse' which was published in 1938 (one year before the oft. quoted paper of Oppenheimer and Snyder), and S. D. Majumdar's work on 'Einstein-Maxwell equations' in 1947, which came to be known as Majumdar-Papapetrov type solutions. A. K. Ray Chaudhuri's contribution to rotating shearing cosmological models in the early 1950's became well-known as Raychaudhuri's equation. The BHU school trained several research workers in general relativity, some of whom continue to be active in places like Ahmedabad, Gorakhpur and Kolhapur. The first student of V. V. Narlikar was P. C. Vaidya whose solutions of a radiating mass are often quoted today. Students of Narlikar have carried today the tradition of general relativity research at BHU.

Presently, much of the research in relativity and cosmology comes from universities like BHU, Gorakhpur, Calcutta, Burdwan, Gujarat, Gauhati, Bangalore, Mysore, Pune, Bhavnagar, Kolhapur, Kumaon etc. Amongst research Institutes mention may be made of S. N. Bose Institute at Calcutta, Matscience at Madras, Raman Research Institute, Indian Institute of Science, Indian Institute of Astrophysics all at Bangalore, PRL at Ahmedabad and TIFR, Bombay. The work in relativity in India is in the areas of exact solutions, Petrov classification of various space-times, astrophysics of highly collapsed objects, accretion discs around black holes, gravitational lens and screens, problems in unified field theory, Brans-Dicke theory and the Einstein Maxwell theory, anisotropic cosmologies and quantum cosmology. The Indian Association for General Relativity and Gravitation was formed in 1969. It has a membership of nearly 175 persons.

Amateur Astronomy after 1950

There has been an increase in the number of active amateur astronomy groups in the third quarter of the 20th century. The most active groups are in Bombay, Calcutta, Bangalore, Madras, Baroda and Goa.[94] Since there is no published information available about general amateur activity in India, it is difficult to prepare a comprehensive report.

Bombay Amateur Astronomers' Association was started in 1976 with R. V. Kamath as the president of the association. The association has built up a member strength of 300. Their main activity includes lecture courses; they regularly bring out a newsletter called M51, encourage members to take up telescope making and observational programmes. Observations of eclipses, lunar occultations, astrophotography, history of astronomy and sky watching programmes are some of the activities followed by them. The association has a Cassegrainian Schmidt telescope 'Celestron 8' and other smaller telescopes. They took part in the total solar eclipses of 1980 in India and 1983 in Indonesia and results of these observations were published in the International Union of Amateur Astronomers.

Bangalore and Bombay groups participated actively in 1980 total solar eclipse which was visible in India. The Bombay group obtained a good colour picture of solar corona using Kodachrome film and a Celestron telescope. The Bangalore amateur group tried to make polarization measurements along with the white light photographs of solar corona. The Bombay amateur group attempted to measure the speed of shadow bands along with the white light photography during the total solar eclipse in Indonesia in May 1983. The Association of Bangalore Amateur Astronomers was established on February 15, 1976. The Association was formally inaugurated on July 4, 1976 by M. K. V. Bappu. They hold meetings every month usually accompanied by a review lecture by some active astronomers. They have conducted courses on basic astronomy and amateur telescope making. They constructed an F/7 Newtonian telescope of 9-inch aperture in 1981 by utilizing purely voluntary contribution in cash and kind.

In Madras the two well known associations are the Madras Astronomical Association and the Yuri Gagarin Club. The Amateur Astronomical Association in Calcutta is in St. Xavier's College. Another active society in Calcutta is the Sky Watching Society, which organizes sky watching camps. It has a 3-inch refracting telescope and 10-inch reflecting telescope.

Amateur astronomy is also encouraged in several universities. Some of the educational institutions equipped with small telescopes are the Presidency College of Madras and Calcutta; Elphinstone College, Bombay; St. Xavier's College, Calcutta and Bombay and St. Joseph's College at Bangalore. Many other educational institutions in the country have sponsored astronomical observations as a part of their routine education programme.

Association for Promotion of Astronomy in India

In 1952, when the Indian Science Congress was held at Calcutta and the University of Calcutta was the host, the new Indian Astronomical Society was formed. This idea was earlier mooted by Saha but unfortunately due to his untimely death in 1956 it could not be carried out. Some important members of the society were A. C. Banerjee, N. R. Sen, S. Basu and M. K. V. Bappu. The principal objectives of the society were to promote and encourage the study of astronomy, astrophysics, astronautics and allied subjects and to bring out a society journal which will carry original results in this field. The society aims to encourage lectures and symposia, undertake popularization of the subject and to improve the facilities for observations. However, due to many reasons the association could not carry out its objectives. It was in 1974 that some of the activities were started again, under the efforts of A. K. Saha and N. C. Lahiri. In 1980, it succeeded in bringing out the first issue of the society publication 'Akash'.[95]

Since the Calcutta Association was not very active, the astronomical community in India was feeling the need for an association for promotion of astronomy and related branches of science in India. Hence the Astronomical Society of India was

formed in 1972 with its headquarters at Osmania University, Hyderabad. To fulfil its objectives it has undertaken various functions like encouragement of the study in all aspects of astronomy and astrophysics, to bring out a journal, to hold scientific meetings for presentation of original research papers and review talks at least once in two years. The society has been very active and has largely succeeded in achieving the objectives. They have undertaken programmes to popularize the science of astronomy among the educational institutions and general public in India through lectures and scholarships and helped inclusion of courses in astronomy in school and university curricula to a limited extent. It has assumed an important task of encouraging amateur astronomy in India. The Bulletin of the association is being published regularly and is considered as one of the leading journals in astronomy in the country.[96]

PUBLICATION

The Kodaikanal Observatory Bulletin (KOB) has long been the medium of publication of research results at Kodaikanal. The first Bulletin was published in the year 1908. These bulletins, in addition to research contributions, contain the date of the solar geomagnetic and ionospheric observations carried out at Kodaikanal.[69] In 1966, the Radio Science Division of the PRL, New Delhi, took over the responsibility of publication of solar and geophysical data. After the formation of the Indian Institute of Geomagnetism in 1971, the new body took over the responsibility of publication of geomagnetic data as a national endeavour. Accordingly the publication of solar geomagnetic and ionospheric data from Kodaikanal was discontinued from 1978 and the bulletins now contain only research papers. In addition to the KOB there was a supplementary publication titled Memoirs of KOB of which only one volume has so far been published. Nizamiah Observatory has been bringing out the contributions of the Nizamiah Observatory since 1962 at periodic intervals. They contain research papers published by the observatory staff.

An important International journal titled *Journal of Astrophysics and Astronomy* has been started by the Indian Academy of Sciences, Bangalore. The publication carries papers of a high standard. The publication signifies a bold venture of the Academy who felt that the expanded astronomical activities in the country deserve a journal of international stature.[97] The journal has a Board of editors drawn from eminent astronomers all over the world. M. K. V. Bappu as its first chairman ably guided the first few years of the journal and set it on its way towards a great future.

As mentioned in earlier section, Astronomical Society of India also regularly publishes a journal titled *Bulletin of Astronomical Society of India* and also the *Memoirs of the Astronomical Society of India*. Two issues of the *Memoirs* have been brought out till now. Four issues of the *Bulletin* are published in a year. The memoirs are special issues brought when new important results containing large amounts of data are to be published.

The Indian Astronomical Society has also been active recently having brought out two issues of their journal 'Akash'.

HIGHLIGHTS OF ACCOMPLISHMENTS IN ASTRONOMICAL RESEARCH IN TWENTIETH CENTURY INDIA

We may conclude this chapter by reviewing briefly the highlights of astronomical research in India during the 20th century. This was a period when the phase of astronomical research changed dramatically and rapidly. On the observational front the period saw the coming in of large telescopes, and more sensitive detectors, which enabled the scientists to reach much further in the universe, thereby expanding the old boundaries. New observational windows in the radio and later in other bands of electromagnetic spectra opened up, bringing a great deal of new information which revolutionized our ideas about the universe. On the theoretical side, Einstein's General Theory of Relativity created a new concept of space and time; the newly acquired capabilities of measurements of starlight with laboratory precision encouraged several schools of theoreticians to realistically model reaction processes in astrophysics. The major glory of advancements in the subject was cornered by nations with developed scientific groups whereas efforts by individual scientists generally took a back seat. India was a dependent colony for more than half of this period, where encouragement to fundamental research had a low priority in the development plans of the state. In spite of all these drawbacks several noteworthy achievements by Indian scientists were made in astronomical research. While some of them were forced to migrate from the country in search of suitable facilities, quite a few had sought to develop the facilities from within. This development perhaps marks the pinnacle of achievements of this period. Most of this work was done in the post-independence period by several groups of young scientists, and resulted in the creation of a chain of observatories. The names of M. K. V. Bappu, G. Swarup and V. Radhakrishnan stand out among this group. If we have to single out the most important achievement in theoretical astrophysics by an Indian scientist it should perhaps be M. N. Saha's Theory of Thermal Ionization. Saha almost single handedly worked out his famous "Ionization Formula". This work has been justly described by Eddington as one of the ten most outstanding discoveries in astronomy and astrophysics since the discovery of the telescope.

D. S. Kothari and his colleagues investigated the properties of degenerate matter and in a series of important papers discussed topics such as opacity coefficient, transport phenomena and ionization of degenerate matter. S.. Chandrasekhar also made important contributions to the same field before migrating abroad. The work on cosmology and relativistic astrophysics pioneered by N. R. Sen in Calcutta and V. V. Narlikar in Banaras yielded several new ideas worth noting. In subsequent years, A. K. Raychoudhuri's "Raychoudhuri Equation" describing rotating, shearing cosmological models and P. C. Vaidya's "Vaidya Metric" for a radiating spherical star stand out as highlights. More recently J. V. Narlikar has made outstanding contributions to the theory of C-field and steady-state cosmology and developed Hoyle-Narlikar Theory of Conformal Gravity in collaboration with Hoyle. In observational astronomy, notable work on the Sun was done by Evershed and Royds at Kodaikanal and on the "Carte due Ciel" programme at Nizamiah Observatory. Later developments were the modernization of solar observational equipment

at Kodaikanal by Das and Bappu, establishment of Naini Tal and Kavalur Observatories by Bappu, and installation of medium size optical telescopes at Rangapur, Naini Tal and Kavalur, with modern observational accessories. A major venture undertaken which is close to completion is the indigenous fabrication of a large optical telescope of 234 cm aperture at Kavalur.

For observations in the radio wavelengths the large cylindrical paraboloid at Ooty is a major construction. The array has also been extended by the addition of more telescopes in interferometric arrangements. The OSRT (Ooty Synthesis Radio Telescope) is one of the most powerful instruments of its type in the world today.

At still longer wavelengths, the Gauribidanur Low Frequency Array possesses one of the largest collecting area available today. This is a unique instrument enabling scientists to probe the universe in the decametre wavelengths.

In the field of X-ray astronomy and cosmic rays, several balloon, rocket and satellite borne payloads have been designed, constructed and launched. This definitely constitutes a big step forward in our scientific efforts.

Similar efforts are under way in the fields of infrared and millimetre wave astronomy. Considerable progress in instrumentation has been achieved.

Several important results in astrophysics have been found by employing these newly developed observational systems. In the field of solar physics, detailed studies of photospheric oscillations have yielded important data on solar seismicity, dynamics of the regions surrounding sunspots and near the temperature minimum have been studied in detail and a long-standing problem of width-luminosity relation of Wilson and Bappu has been solved. Observations during the three total solar eclipses have confirmed the existence of cooler regions in the lower corona. Studies of rapid features in solar decametric bursts have thrown considerable light on the mechanism of these phenomena.

In studies of solar system astrophysics, several epoch-making discoveries have come out of a series of planetary occultations. Discoveries of the rings of Uranus and the outer rings of Saturn were made from observations done with the telescopes at Kavalur and Naini Tal. Interplanetary scintillation studies, and the observations of progressive change in cometary spectra with varying heliocentric distances have given a much clearer picture of the interplanetary medium.

In extragalactic studies, impressive results are obtained by S. M. Alladin and his colleagues in modelling theoretically the dynamical interactions between galaxies. Observational and interpretative work of good standard on peculiar and radio galaxies and quasars is being carried out at the Radio Astronomy Centre of TIFR and at Indian Institute of Astrophysics. While studies in stellar physics, interstellar matter and galactic structure are avidly pursued in all the optical observatories and by groups in TIFR and PRL, the radio observations are continuing at Ootacamund

and Gauribidanur. A strong group on the studies of pulsars and supernova remnants, as also on interstellar molecular clouds, is emerging at the Raman Research Institute.

Narration of achievements by Indian scientists will be incomplete, if note is not taken of the outstanding work done by several scientists, who either migrated abroad or did a significant portion of their work while abroad. Top of the list is, of course, occupied by the Nobel Prize winning Indian born scientist, S. Chandrasekhar. A major part of the original discoveries of M. K. V. Bappu in stellar spectroscopy was achieved while still in USA. So was the monumental work of M. R. Kundu and K. Nandy whose outstanding contributions were made while working abroad. There were several others, notably H. K. Sen, T. K. Menon, S. S. Kumar, V. Radhakrishnan who have left indelible marks in the international astronomical literature by their significant achievements.

When the decision was taken by IAU to name newly discovered lunar craters on the far side of the Moon after the departed scientists, names of seven eminent scientists from India were selected. The names are: J. C. Bose, P. C. Ray, H. J. Bhabha, M. N. Saha, S. K. Mitra, A. K. Das, and J. B. S. Haldane. In a later meeting three more names were added and those were C. V. Raman, V. A. Sarabhai and S. N. Bose. Besides these, the Moon's surface also bears the names of three British astronomers who spent the best years of their lives in the persuit of science in India. The names are those of N. R. Pogson, J. Evershed and T. Royds. These are token salutations of the International Community of astronomers to the great minds who have enriched Indian science in the present century.*

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APPENDIX

A Chronology of Astronomical Event in India in The Twentieth Century

1901 Establishment of Nizamiah Observatory
Solar Observations started at Kodaikanal

1904 Spectroheliogram sequence started at Kodaikanal

1908 Nizamiah Observatory taken over by Nizam's Government

1909 Evershed effect discovered

1910 Apparition of Comet Halley
Astronomical Society of India established

1912 Nizamiah Observatory joins Carte du Ciel programme

1913 Evershed carried out solar experiments in Srinagar, Kashmir

1920 M. N. Saha's paper on ionization in solar chromosphere

1921 Saha's paper on stellar spectra

1932 D. S. Kothari's paper on degeneracy in stellar core

1936 Royd's measurement of solar limb spectra

1937 Saha describes the idea of stratospheric solar observatory

1945 Saha Committee on Astronomy
Tata Institute of Fundamental Research established
Spectroscopic observations at Nizamiah Observatory

1951 UP State Government decides on an astronomical observatory

1952 Radio observations of the Sun started at Kodaikanal
Indian eclipse expedition to Iraq

1953 Physical Research Laboratory established

1954 Astronomical Observatory at Varanasi started
Kodaikanal joins International Mars Programme

1955 Naini Tal Observatory started observations
Indian eclipse expedition to Ceylon

1957 Indian Astronomical Ephemeris released
Intensified solar observations undertaken in connection with IGY

1963 First rocket flight from Thumba
Solar Eclipse Observations in Maine, USA

1964 Centre of Advanced Study in Astronomy was opened at Osmania University
India admitted as a regular member of IAU

1965 Solar magnetograph observations started at Kodaikanal
TIFR takes up Radio Astronomy Programme

1967 Kavalur Observatory established

1968 Rocket flight with X-ray payload from Thumba

1970 Indian Eclipse Expedition to Mexico results in new coronal data
Ooty Radio Telescope commissioned
Names of seven Indian scientists put on Moon

1971 Formation of Indian Institute of Astrophysics
First photoelectric observation of planetary occultation from India
International Mars programme observations at Kavalur

1972 Two one-metre telescopes installed at Naini Tal and Kavalur
Ganymede atmosphere detected
Raman Research Institute starts Astrophysical research
Astronomical Society of India constituted

1974 IIA starts on 234 cm telescope project
Vedhashala undertakes observational programmes
Aryabhata with X-ray Payboard launched.

1975 Computer controlled spectrum scanner commissioned at Kavalur

1976 Three more Indian names put on moon

1977 Discovery of Rings of Uranus

1978 PRL starts 122 cm IR Telescope project

1979 M. K. V. Bappu elected as President IAU
First detection of IR bursters at Kavalur

1980 Total Solar Eclipse in India
Balloon-borne far IR telescope launched

1983 Indian Eclipse Expedition to Indonesia

1984 Discovery of Outer rings of Saturn

NOTES AND REFERENCES

1. A SURVEY OF SOURCE MATERIALS

[1] For a succinct and fully documented analysis of the archaeology of ancient India, see S. N. Sen in *A Concise History of Science in India,* 1-15.
[2] See Marshall (1); Vats; Mackey (1), (2).
[3] For the astronomical interpretation of seal 2430, see Bag, (3).
[4] *RV* 1. 105.18, as explained in Yaska's *Nirukta* 5.4.20.1; see also Roy, S. B. (1), 1-4.
[5] Roy, S. B. (1), 14-35.
[6] Roy, S. B. (1), 118-37.
[7] *YV (Śukla),* 17.2. ff.; *YV* (*Kṛṣṇa*), 4.4.11.4; 7.2.20.1.
[8] For a documentation of Vedic references to numbers in the decimal system, see Macdonell and Keith, *Vedic Index* under *Daśan,* (Vol. I, 342-44).
[9] See *YV* (*Kṛṣṇa*), 7.4.8; *Kauṣ Br,* 19.3; *Taṇḍ Br,* 5.9; Sen Gupta, P. C. (b), article 'Solstices in Vedic Literature', 155-74.
[10] *RV.* 4.50.4; 10.23.1.
[11] *RV.* 1.105.10.
[12] 'The solar eclipse in the *Ṛgveda* and the date of Atri', in Sen Gupta, P. C. (6), 101-31.
[13] For a documentation of Vedic Astronomy, see Sarma, K. V. (7), 1-20.
[14] *YV (Śukla)* 3.10, *Tait. Br.* 3.4.4.
[15] *YV (Śukla)* 30.20; *Tait. Br.* 3.4.15.
[16] Jain, L. C., 137-46.
[17] Shukla, K. S., (3), 83-105; 'Glimpses from the *Āryabhaṭasiddhānta*', *Indian Journal of History of Science,* **12**, 194-99, 1977.
[18] Pingree (9), 103-23.
[19] Pingree, (8), 172-241.
[20] Pingree, (14), 23-24.
[21] On the advantage accruing from the derivation of such an epoch, see Sarma, K. V., Introductions to his editions of the *Sphuṭacandrāpti* and *Veṇvāroha* of Mādhava.
[22] For a documented account of these texts see Pingree, (14), 41-46.
[23] For a detailed and documented survey of the field, and the works noticed in this section see Sarma, K. V. (5), Pingree, (14), 47-51.
[24] For a discussion on these verses, see Shukla (3), 83-105.
[25] Shukla (9), 181-85.
[26] Middleton, 831-40.
[27] See Khan, Ahmad Saeed, *A Bibliography of the Works of Abu'l-Raihān Al-Bīrūnī.*
[28] Khan, *Bibliography,* G 1, No. 93.
[29] Khan, *Bibliography,* G 1, No. 5.
[30] Khan, *Bibliography,* G 1, No. 104.
[31] Rahman, 599-613.
[32] Rahman, 607.
[33] Rahman, 607.
[34] Rahman, 608.
[35] Rahman, 377-78.
[36] Rahman, 330·
[37] Rahman, 330.
[38] Rahman, 306-7.
[39] Rahman, 348-49.
[40] Gupta, 219-36.

41 Sharma, M. L., 244-51.
42 Bahura, G. N., 58. For other translations, see Bag, (2) 79-93.
43 See Kaye (1), (2) Behari and Govind, Govind.
44 Bahura, G. N., 57.
45 See Kaye (1) and (2); Hunter (3); Sharma, Shakti Dhara; Singh, Prahlad.

2. DEVELOPMENT OF ZĪJ LITERATURE IN INDIA

1 *At-Taṣrīh* 5-17,
2 *Sharḥ-i Chaghmīnī*, 24-28.
3 *Sharḥ-i Chagmīnī*, 30-31.
4 When Qurānic Verse 111-169 was revealed commending the thinking of those who reflect upon natural phenomena such as succession of day and night etc., the prophet exclaimed: "Woe to one who recites this verse in between his jaws, but ponders not upon that it implies, thereby enjoining upon the faithful and meaningful study of celestial and terrestrial phenomena."
5 *Tabaqāt-ul-Umam*, 75.
6 *Murūj-alā-Dhahal wa Maʿādin-ul-Jawāhir*, 242.
7 *Tabaquāt-ul-Umam*, 78.
8 *Ibid*, 75, 79.
9 *Tārīkh-ul-Hukamā'*, 357.
10 *Maqālīd ʿIlm al-Ha'yat*, 189a.
11 Ibn al-Haytham propounded the theory of solid sphere in place of that of imaginary circles of planetary orbits (See *Tabṣira*).
12 *Mujʿam al-Udabā.ʿ* 186.
13 *Al-Kāmil fī at-Tārīkh, X*, 98.
14 *Sharḥ Chaghmīnī* is still prescribed in the advanced syllabus of astronomy in Arabic Madrasas.
15 *Habīb-us-Siyar fī Akhbār-i- Afrād-il-Bashar*. 306.
16 *Zīj-i Īlkhānī*.
17 Humāyūn would, whenever he found time, discuss with his mathematician companion the astronomical content of *Durrat-ut-Taj* by Quṭb-ud-dīn Shīrāzī.
18 Many commentaries on Ṭūsī's *Tadhkira* by Niẓām-ud-dīn A'araj, and Mīr Sayyed Sharīf; on Chaghmīnī's *al-Mulakhkhas fī al-Hayʿat* by Qāḍī Zādah Rūmī and on Ṭūsī's *Zīj-i Īlkhānī* by Niẓām-ud-dīn Aʿaraj are found in Indian libraries, which signifies that they were generally read or consulted in this country.
19 *Ḥabīb-us-Siyar*, Vol. III, Part IV.
20 *Zīj-i Ulugh Beg*, fol. 2-a.
21 *Matlaʿ-us-Sʿadayn*, 421-423.
22 *Zīj-i Ulugh Beg*, fol. 2-a.
23 *Ibid*, fol. 2-a.
24 *Ā'īn Akbarī*, I, 211.
25 *Sirāj-ul-Istikhrāj* of Mullā Farīḍ.
26 *Zīj-i Shāhjahānī* of Mullā Farīḍ.
27 *Ibid*, fol. 3a.
28 *Tabaqāt-ul-Umam*, 78.
29 *Kitāb-ul-Fihrist*, 275.
30 *Az-Zīj-ul-Kabīr-ul-Ḥakīmī*, 141.
31 *Tārīkh-ul-Ḥukamā*, 357.
32 *Ibid*, 358.
33 *Tabaqāt-ul-Umam*, 78-79.
34 *Tārīkh-ul-Ḥukamā'*, 170.
35 *Kitāb-ul-Fihrist*, 279.
36 *Tārīkh-ul-Ḥukamā*, 280.

37 *Ibid*, 280.
38 *Kitāb-ul-Fihrist*, 283.
39 *Qānūn Ma'sūdī*, I, 124.
40 *Muj'am al-Udābā'*, XVII, 186.
41 *Tārīkh-ul-Ḥukamā'*, 226.
42 *Zīj-i-Īlkhānī*.
43 Dedicated to Sultan Masūd, son and successor of Sultān Maḥmud of Ghazna.
44 Al-Bīrūnī's letter to one of his friends listing his works. This letter has been appended by Sachau to his edition of *Al-Athār al-Bāqiya*.
45 *Tārīkh-ul-Ḥukamā'*, 245.
46 *Zīj-i Īlkhānī*, fol. 3a. X
47 *Al-Kāmil-ut-Tawārikh*, X, 98.
48 *Tatimma Ṣuwan-ul-Ḥikma*, 161-62.
49 *Zīj-i Īlkhānī*, fol. 2a.
50 *Ibid*, 2a.
51 *Zīj-i Khāqānī*.
52 *Matla-'us-Sa'dayn*, 422.
53 *Zīj-i-Khāqānī*, fol. 2-a.
54 Catalogue of Central State Library *(Fihrist Kutub Khāniah Ashrafīya)*, III, 338, Hyderabad, 1919. But the title of the book is simply *Zīj-i Ulugh Beg*, which anomaly need to be checked by a careful study of the text.
55 *Zīj-i Tadīd Sulṭānī* of Ulugh Beg Garkan, generally known after author's name as *Zīj-i Ulugh Beg*, also mentioned by Jai Singh in the preface of *Zīj-i Muḥammad Shāhī*, as *Zīj-i Jadīd-i Sa'īd Gurgānī*.
56 *Matla-'us-Sa'dayn*.
57 *Zīj- Ulugh Beg*.
58 *Dīwān*, 332-33.
59 *Ā'īn-i Akbarī*, I, 211.
60 *Zīj-i-Shāhjahānī*, fol. 2b, 3a.
61 *Zīj-i Muḥammad Shāhī*, fol. 1b.
62 *Mu'jam-ul-Udabā'*, XVII, 186.
63 *Kitāb-al Hind* of Al-Bīrūnī, 270.
64 *Kitāb Taḥdīd Nihayat al-Amākin*, 222-23.
65 *Dīwān*, 420.
66 *Qīrān-us-Sā'dayn*, 164-67.
67 *Tārīkh Fīroz Shāhī*.
68 *Ibid*, 363.
69 *Sirat-i Fīroz Shāhī*, 294-96, Ms. No. 111.
70 Kaye (4), 3.
71 Ulugh Beg's observatory at Samarqand began to be built in 823 A.H. (1420 A.D.) whereas Fīroz Shāh Bahmanī ordered in 810 A.H. (1407 A.D.) for an observatory to be built at Balaghat (*vide Farishta: History of India*, I, 316).
72 *Farishta*, 308.
73 *Babar Nāmah of* Zahīruddīn Bābur, 412.
74 *Akbar Nāma* of Abul Faḍl, I, 120, 122.
75 *Ibid*, 128.
76 *Ibid*, 368.
77 *Ibid*, 368.
78 *Dabistān-ul-Madhāhib*, 328.
79 *Ā'īn-i Akbarī* of Abul Faḍl, II, 221.
80 *Ibid*, I, 82.
81 *Ibid*, III, 8-60.
82 Tuzuk-i Jahāngīrī, 307, 329,335
83 *'Amal-i Ṣālih*, I, 1361; also *Zīj-i Shāhjahānī* fol. 2a.
84 *Ma'āthir-ul-Kirām*, 300.
85 *Tadhkira Baghistān*, 681a.

86 *Ṣuwar-ul-Kawākib* (Persian translation), Persian Ms. No. 31 (Aligarh), 1b-2a.

87 *At-Taṣrīḥ*, 2; it has been lithographed many times, as it is prescribed in the syllabus of Arabic Madrasas. It is still prescribed as astronomical text-book for ʻĀlem Examination of U.P.

88 *Bāb Tashrīh al-Aflāk* was lithographed in the early part of this century, but printed copies are very rare.

89 *Zīj-i Muḥammad Shāhī*, 2a.

90 The author commenced its writing on (11th of Ṣafar) 1248 A.H.—A.D. 1833 and completed it in the following year i.e. A.D. 1834. The book was printed under the personal supervision of the author himself in 1835 lithographically at Calcutta.

91 A friend of mine has placed the xerox of the autograph copy of the manuscript at my disposal. From the colophon at the end, it is understood that is was completed in the month of Ṣafar 1311 A.H. (*c.* A.D. 1893).

92 Storey, II, pt. I, 52.

93 *Āʼīn-i Akbarī*, I, 211; *Zīj* No. 72.

94 Storey, II, pt. I, 52.

95 *Zīj-i Jāmiʻ*.

96 *Zīi-i Jāmiʻ*, fol. 1b.

97 *Ibid*, fol. 3a.

98 *Ibid*, fol. 3a.

ʻol. 3a.

100 *Ibid*, tol, 3a.

101 *Ibid*, fol. 1b.

102 *Ibid*, fol. 1b.

103 *Maʼāṭhir-i Raḥīmī*, III, 9.

104 *Ibid*, 9.

105 *ʻAmal-i Ṣāliḥ*, I, 361.

106 Charles, II, 460.

107 *ʻAmal-i Ṣāliḥ*, I, 361.

108 *Zīj-i Shāhjahānī*, fol. 3a.

109 *ʻAmal-i Ṣāliḥ*, I, 362.

110 Charles, II, 454.

111 *Zīj-i Shāhjahānī*, fol. 4a.

112 *Zīj-i Muḥammad Shāhī*, fol. 1b.

113 *Ibid*, fol. 1b.

114 *Ibid*, fol. 1b.

115 *Ibid*, fol. 2a.

116 *Ibid*, fol. 2a.

117 *Ibid*, fol. 2a.

118 *Ibid*, fol. 2a.

119 *Ibid*, fol. 81a.

120 *Āthār-uṣ-Sanādīd*, 316.

121 *Zīj-i Muḥammad Shāhī*, fol. 81a.

122 *Ibid*, fol. 81a.

123 *Ibid*, fol. 82b.

124 *Ibid*, fol. 4b.

125 *Nuzhat-ul-Khawāṭir*, VII, 350.

126 *Jāmiʻ Bahādūr Khānī*, 720.

127 *Ibid*, 3.

128 *Zīj-i Bahādūr Khānī*, I am grateful to Prof. S. M. R. Ansari for putting at my disposal his notes and xerox of the *Zīj*.

129 *Ibid*, fol. 2a.

130 *Ibid*, fol. 2b.

131 *Ibid*, Chapter 7, on Astrology.

132 Rahman *et al*, 323, 377.

133 Old Catalogue of Persian Manuscripts in Raḍā Library (Rampur), Hay'at No. 1221.

134 *Fihrist Kutub Khāna-i Āṣifiya* (Central State Library) Hyderabad, I, *Riāḍī*, No 112.

135 *Ibid, Riāḍī,* 301.
136 Rahman *et al,* 378.
137 Old Catalogue of Persian Manuscripts in Raḍā Library (Rampur), Hay'at No. 1224.
138 A xerox of the autograph copy of the manuscript is with the writer. The original was written in 1892-93.

3. SURVEY OF STUDIES IN EUROPEAN LANGUAGES

1 Sen (7), 58.
2 Translated into German by A. Bjornbo and R. Besthorn with commentaries by H. Suter under the title Die astronomischen Tafeln des Muḥammed ibn Mūsā in der Bearbeitung des Maslama ibn Ahmed al-Madjriti und der latein Ubersetzung des Athelard von Bath. English translation by O. Neugebauer "Astronomical tables of Al-Khwārizmī", Historisk filosofiske skrifter u... Kongelige Danske Videns. Selskab, 4, nr. 2., Kbenhavn 1962.
3 Neugebauer and Schmidt, 221-228.
4 Bailly, 3.
5 Le, Gentil, *Mémoires de l'Academie Royale des Sciences,* **8**, 279-362, 1699.
6 Burgess (J) (1), 724-25.
7 Bayer, T. S., in *Historia Regni Graecorum Bactriani,* 1738.
8 Woolf, 129.
9 Burgess (J) (1), 728-29.
10 'Il faut donc que ces observations aient été faites ailleurs, et on ne peut guères se refuser a croire qu'elles ont été faites dans l'Inde ou les chaldiens semblent avoir emprunté les premiére elements de leur Astronomie,' *Astron. Ind.* 296. Again, "Il en résulte par consequent que les Astronomes d'Alexandrie tiennent des Indiens les connaissance primitives et fondamentales de la théorie de la lune", *Ibid,* 300.
11 *Esprit des Journeaux,* November 1787, 80.
12 Playfair (1), 135-192.
13 Playfair (2), 159-163.
14 Davis (1), 235.
15 Burgess (J) (1), 731.
16 Marsden, 583.
17 Davis (2), 209-27; *Burgess* (E), *Sūryasiddhānta,* I, 55, note.
18 Jones (1), 289-306.
19 Bentley (2), 537-88.
20 Bernoulli, I, 316.
21 Barker, 598 ff.
22 Hunter (3), 183-84.
23 Colebrooke (2), 345, 349-51.
24 Colebrooke (2), 345.
25 Colebrooke (2), 373.
26 Colebrooke (3), 374-382.
27 Colebrooke (3), 401.
28 Colebrooke (4), 429.
29 Colebrooke (4), 467-68.
30 Colebrooke (4), 455.
31 Warren, preface, X.
32 Warren, 118.
33 Kriya tâvuri jituma kulīra leya pāthona jūka kaurpyākhāḥ/(Taukṣika ākokero hṛdrogaścāntyabhaṃ cettham,//(*Vṛhajjātaka,* i, 8).
34 *Indische Studien,* ii, 254, 261.
35 Wilkinson, 504-519.
36 Roer, 53-66.

[37] Biot, (2), 7-145.
[38] The text with a Bengali translation appeared at a much earlier date in 1842 from Calcutta (Sen (6), 219.)
[39] Biot (2), 157.
[40] 'Recherches sur l'Ancienne Astronomie chinoise, publiées à l'occasion d'un mémoire de M. Ludwig Ideler sur la chronologie des chinois', *Journal des Savants,* December 1839-May 1840.
[41] Weber (1), II, 274.
[42] Weber (1), II, 276.
[43] Weber (1), II, 279.
[44] Whitney (1), 17.
[45] Whitney, 59.
[46] Whitney, 60-61.
[47] Burgess (E) (2), 317.
[48] Burgess (E) (2), 325.
[49] Thibaut (4), 151-52.
[50] Bahu Daji.
[51] Kern, *JRAS,* **20**, 371-87.
[52] Colebrooke, (1), 469-70.
[53] Weber (2), 10, 14.
[54] Thibaut (1) 418.
[55] Thibaut (1) 423.
[56] Weber, *Ind. Stud.* 10, 264 ff.
[57] Burgess (J), 754 FN.
[58] Thibaut (3), Introduction, VI.
[59] Thibaut (3), Introduction, XLVI.
[60] Thibaut (3), Introduction, XLVII.
[61] Thibaut (3), Introduction, XXVI-XXVII.
[62] Thibaut (3), Introduction, XXXVIII.
[63] Thibaut (3), Introduction, L.
[64] Thibaut (3), Introduction, LIV.
[65] Sachau, Al-beruni's India, Preface, XXVIII.
[66] Sachau, *Alberuni's India,* Preface xxix.
[67] Sachau, *Alberuni's India,* II, 15.
[68] Sachau, *Alberuni's India,* II, 33-34.
[69] Sachau, *Alberuni's India,* II, 67.
[70] Sachau, *Alberuni's Idia,* I, 153.
[71] Bühler, 239, informnsus how he came to know of Jacobi and Tilak's papers prior to their publications.
[72] Jacobi, 154.
[73] Jacobi, 156.
[74] **Tilak, 26.**
[75] Tilak, 56-57.
[76] Tilak, 76.
[77] Tilak, 94.
[78] Bühler, 246.
[79] Whitney, 361-69.
[80] Thibaut (5), 87.
[81] Thibaut (6), 9 ff.
[82] Fleet, 514-18.
[83] Fleet, 514-18.
[84] Keith (1) 794-800.
[85] Shamasastry (2), 26-32; 45-71; 77-84; 117-124.
[86] Keith (2), 627-40.
[87] Datta, 59-74.
[88] Sengupta (1), 1-56.
[89] Blachére, 43-44.

[90] Blachère, 103.
[91] Neugebauer (4), 166-173.
[92] Neugebauer (2), 166-167.
[93] Neugebauer (3), 252-276.
[94] Neugebauer (5), 174-187.
[95] Neugebauer (7), 10.
[96] Neugebauer (7), 23.
[97] Neugebauer (7), 124.
[98] Neugebauer and Pingree, I, 10.
[99] Neugebauer and Pingree, I, 13.
[100] Sen (8), 343.
[101] Neugebauer and Pingree, I, 16.
[102] Shukla (1), 115 ff.
[103] Pingree (1), 282-84.
[104] Pingree (13), 411-412.
[105] Pingree (13), 197.
[106] Pingree (2), 234.
[107] Pingree (2), 238.
[108] Pingree (11), 80-85.
[109] Pingree (12) 28.
[110] Pingree (8),, 172.
[111] Pingree (9), 106.
[112] Pingree (7), 97-125.
[113] Van der Waerden (2), 220.
[114] Van der Waerden (4), 221, 224.
[115] Wirth, 29-43.
[116] Van der Waerden (12) 35-43.
[117] Van der Waerden (12),, 42.
[118] Van der Waerden (14), 117-18.
[119] Some of the earlier contributions of van der Waerden on the subject include 'Das Grosse Jahr and die Ewige Wiederkehr', *Hermes,* **80,** 129-155, 1952; 'Das Grosse Jahr des Orpheus', *Hermes,* **81,** 481-84, 1953; 'Ausgleichspunkt Methode der Perser und indische Planetenrechnung', *Archive Hist. Exact Science,* I, 107-121, 1961; (with E. S. Kennedy) 'The World Year of the Persians; *J. Amer, Oriental Soc,* **83,** 315-327, 1963.
[120] Van der Waerden (13), 362-63.
[121] Van der Waerden (13), 369.
[122] Van der Waerden (13), 373.
[123] Van der Waerden (13), 376-77.
[124] Van der Waerden (14), 121.
[125] Van der Waerden (14), 122.
[126] Van der Waerden (14), 123-24.
[127] Van der Waerden (14), 129-30.
[128] Billard (1), 15-16.
[129] Billard (1), 19.
[130] Billard (1), 59.
[131] Billard (1), 80.
[132] Billard (1), 82.
[133] Billard (1), 83.
[134] Van der Waerden (15), 52.
[135] Van der Waerden (15), 53.
[136] Van der Waerden (15), 53.
[137] Van der Waerden (15, 54.
[138] Billard (1), 140.
[139] Van der Waerden (15), 57.
[140] Van der Waerden (15), 58.

4. ASTRONOMY IN INDUS CIVILIZATION AND DURING VEDIC TIMES.

1 Parpola *et al, Further Progress in the Indus Script Decipherment;* also UNESCO Courier, December 1973, 31-33.
2 Asfaque, 149-93.
3 Heras, 100.
4 For the quotations, *vide* Asfaque, 183-84.
5 *Tait. Br.* 3. 1. 4.
6 *Śat. Br.* 2. 1. 2-3.
7 Apte, 1-16.
8 Asfaque, 164, 183.
9 AV. 19. 7.
10 Dikshit, 133-34.
11 Pāṇini, 4. 2. 22; 4. 3. 50; 5. 4. 110.
12 Chapter 106 and 109, Anuśāsanaparva.
13 Sachau's *Al-Bīrūn*[9]*'s India,* **2,** 9-10.
14 *AV.* 19. 7.
15 *Taiț Saṃ.* 4. 4. 10; *Mait. Saṃ.* 2. 13. 20. and so on.
16 For Nirayana longitude, *vide,* Lahiri, 41; Ephemeris, p. 41, Calcutta, 1983; Nirayaṇa longitude + 23° 379″. 7 = Sāyana longitude.
17 *RV.* 10. 190. 2-3.
18 *Tait. Br.* 1. 1. 3; 7. 1. 5.
19 *Tait. Up.* 2. 1.
20 *Tait. Br.* 2. 8. 9.
21 *RV.* 10. 10-14.
22 *RV.* 1. 52. 11.
23 *Tait. Saṃ.* 7. 5. 23.
24 *RV.* 1. 105. 10.
25 *RV.* 4. 50. 4.
26 *RV.* 10. 55. 3.
27 *RV.* 1. 24. 10.
28 *RV.* 10. 14. 11.
29 *RV.* 10. 63. 10.
30 *Sat. Br.* 2. 1. 2. 4; *Tāṇḍa Mahābrāhmaṇa* 1. 5. 5.
32 *RV.* 1. 164. 14; 8. 58. 2.
33 *RV.* 1. 95. 3; *Ait. Brāh.* 2. 7.
34 *RV.* 1. 14. 3.
35 *RV.* 9. 59. 2.
36 *Taiț Saṃ* 3. 4. 7. 1.
37 *RV.* 9. 71. 9.
38 *RV.* 10. 85. 19.
39 *RV.* 2. 32. 4; 5. 42. 12; *Taittirīya Saṃhitā* 1. 8. 8. 1.;
40 *Tait. Br.* 3. 10. 1-2.
41 *Taiț. Br.* 3. 10. 1-4.
42 *Āiț Br.* 32. 10.
43 *Śaț Br.* 1. 6. 4. 18-20.
44 *RV.* 1. 164. 49; 8. 48. 7.
45 *Tait. Saṃ.* 7. 5. 1.
46 *Nidāna Sū.* 5. 11-12.
47 *RV.* 1. 25.9.
48 *Tait. Saṃ.* 7. 5. 6.
49 *RV.* 1. 25. 8.
50 Sen (10), 76.
51 *Tait. Br.* 3. 10. 4.

52 *RV*. 7. 103. 7-8.
53 *Vāj*. *Saṃ*. 26. 45; 30. 16.
54 *RV*. 1. 15.3.
55 *Tait*. *Saṃ*. 4. 4. 11.
56 *Kauṣ Brā*. 19. 3.
57 *Tait*. *Saṃ*. 6. 5. 3.
58 *RV*. 10. 2. 7; 10. 18. 1; 10. 98. 11.

5. POST-VEDIC ASTRONOMY

1 Bṛhaspatiḥ prathamam Jayamanaḥ Tiṣyam Nakṣatram abhisambhabhūva. (*Taittirīya Saṃhitā* 31.5 & *Tāṇḍya Brāhmaṇa*).
2 "Conjunction of Jupiter with δ Cancri" by S. D. Sharma, paper reported in History of Scinece Congress in Edinburgh, Scotland; (U.K.), 1977, communicated and accepted with revision of diagrams for *I.J.H.S.*
3 It may be pointed out that only this date has support from internal evidences within the text of *V. J.* The linguistics based and other evidences have very little value. The report of winter solstice in the beginning of Śravaṇa asterism is a naked eye report of this date. This is the actual happening reported and a back calculated date when the rate of precession was not known. The text belongs definitely to about 14th or 15th century B.C. in the old oral (*Śruti*) tradition.
4 *Bṛhat-saṃhitā* and *Bhadrabāhu Saṃhitā* have separate chapters on kinematics of different planets, comets and meteors. In addition to these, scattered materials are available in the *Purāṇas, Mahābhārata* and other Sanskrit literature.
5 *Bhadrabāhu Saṃhitā*, Chapter 7.
6 "Mathematical Analysis of Post-Vedāṅga Pre-Siddhāntic data in Jaina Astronomy." Ph.D. thesis by S. S. Lishk under the supervision of S. D. Sharma, Punjabi University, Patiala (1977).
7 "Halley's comet—past and recent apparitions," paper by S. D. Sharma presented in the Astronomical Society of India Conference held in Bombay (Nov. 1984).
8 "Mathematical analysis of Post-vedāṅga Pre-Siddhāntic data in Jaina Astronomy", Ph.D. thesis by S S. Lishk under the guidance of Dr. S. D. Sharma of Punjabi University, Patiala (Pb) (1979). The Jaina Canonical text *Sūrya-prajñapti* is shown to belong to 2nd century B.C. The contents belong to these dates. This fact has also been claimed in commentary on *Sūryaprajñapti* by S. D. Sharma (In Sanskrit & English) (To be published).
9 *Brāhmasphuṭa-siddhānta*.
10 Sharma (S.D.) (2), 33-38.
11 Commentary on *Sūrya-prajñapti* by Malayagiri, Prābharta-1. Prabhṛta-Prabhṛta-2.
12 Neugebauer and Pingree, Introduction, 12-13.
13 Neugebauer and Pingree, Introduction 12.
14 Such plots using mean and true positions were prepared for proving the modernity of the present version of *Sūrya-siddhānta* by the author using computer programs in order to report in *Śāstrīya Pañcāṅga Mīmāṃsā*. One can also verify the claim easily by using Kannu Pillai's ephemerism and other modern theoretical ephemerides of past centuries.
15 Here we give two examples of too far stretched problems.
(a) David Pingree gave a hypothesis in which he tried to prove *Vedāṅga Jyotiṣa* to be of Babylonian origin, on the basis of the ratio 3:2 of maximum to minimum length of the day adopted in this text. But if allowance is made for recording time using clepsydra, the application of Bernoulli's or Poricelli's theorem for change of rate of flow of water under gravitational pressure, one can easily conclude that the text belongs to Ujjainī. Hence Prof Pingree's hypothesis is very much questionable (Sharma and Lishk, 165-176).
(b) In the case of Bījopanaya by Bhāskarācārya, T. S. Kuppanna Sāstri tried to prove this to be a forgery because the text has errors, but by taking into consideration, the experimental arrangements and the points of lunar orbit where Bhāskarācārya made his observations, one can believe that such confusing results were natural. One can easily see the genuineness of the text (see *Śāstriya Pañcāṅga Mīmāṃsā*).

[16] Dixit (S B.) (4), 267.
[17] *Brāhmasphuṭa-siddhānta.*
[18] This chapter (or text) was not available to S. B. Dixit. (See *Bhāratīya Jyotiṣa* (Hindi), page 301.
[19] *Siṣyadhī-vrddhida-tantra.*
[20] For details, see *Śāstrīya Pañcāṅga mīmāṃśā* by S. D. Sharma and P. V. Sharma.
[21] For details see *Bhāratīya Jyotiṣa* by B. S. Dixit.
[22] *Siddhānta Samrāṭ* by Jagannatha.
[23] Dixit (S. B.) *Bhāratīya Jyotiṣa* (Hindi), 310.
[24] *Vākya-karaṇam* with the commentary by Sundar Rāja.
[25] *Cāru Candra Vākyāni* and *Vākya-karaṇa* have very interesting sentences, with astronomical meanings as well as other meanings connected with the social life of people.
[26] *Śāstrīya Pañcāṅga Mımāṃsā* chapter on "Bīja-saṃskāras."
[27] Edited by Dr Bloch and Syed Samad Hussain Rizvi of Pakistan.

6. THE YUGA SYSTEM AND THE COMPUTATIONS OF MEAN AND TRUE PLANETARY LONGITUDES

[1] *Yuge sūryajña-śukrāṇām Khacatuṣkaradārṇavāḥ, SūSi* i. 29.
[2] *SūSi,* 1. 59.
[3] *Kalpo brāhman ahaḥ proktam śarvari tasya tāvatt.*
[4] *SiŚe,* ii. 58.
[5] For a proof of this please refer to the author's English commentary on Bhāskara's *Siddhānta-Śiromaṇi* page 232.
[6] *SiŚi, Golādhyāya, Madhyagati-vnsanā,* 24.
[7] *SūSi,* i, 50, 51.
[8] *SūSi,* i, 68.
[9] *mandam karma ekam arkendoḥ. SūSi,* ii. 43.

7. ECLIPSES, PARALLAX AND PRECESSION OF EQUINOXES

[1] *Jaina Siddhānta Bhāskara;* Nemicandra on 'Jaina Pañcāṅga', Vol. 3, no. 2.
[2] Petri, (5), 91-98.
[3] *Sūryaprajñapti,* 20-6.
[4] *Bhagavati-Sūtra,* 3-12-6 and *Sūrya Prajñapti,* 20-12-13 (20th *prābhṛta,* 12th *prābhṛta—prābhṛta* and 13th *gāthā*).
[5] Bhatta, *Bhāratīya Jyotiṣa Sāstra,* Vol. 3, 87. In siddhāntas (like the *Sūrya-siddhānta* and others), *Vyatipāta* is referred to as dark coloured—*sākṛṣṇa* or *dhumravarṇa*) and auspicious for *mantra siddhis* etc. (like eclipses).
[6] Kuppanna Sastry. (3), 107-125.
[7] *Jyotiskarandaka* of Vallabhācārya, *gāthā,* 292.
[8] *Sūryaprajñapti,* 20-12-13.
[9] *Sūryaprajñapti,* 20-9-10.
[20] *Sūryaprajñapti,* 20-12-13.
[11] 'Mathematical analysis of post-Vedāṅga pre-siddhāntika data in Jaina astronomy',—Ph.D. thesis of S. S. Lishk (1977).
[12] The information is based on two papers by Kuppanna Sastry on lunar and solar eclipses, which appeared in the magazine of the Maharaja College at Pudukkotta (T.N.) in March 1951 and March 1952 and which the author had the privilege to obtain from late Sastry. See also Sastry's 'Historical development of certain astronomical processes' *IJHS,* 4, Nos. 1 and 2.
[13] *Sūrya-siddhānta, Vijñāna-bhāṣya,* published by Vijnana Parisad, Allahabad (1940), pp. 779-826.
[14] See ref. 13 at the end of chapters on lunar and solar eclipses.

15 *Sūrya-siddhānta,* Eng. trans. by Burgess, appendix.

16 Sharma and Sharma, *Sāṣṭrīya Pañcāṅga Mīmāṃsā,* 76.

17 Sharma and Sharma, *Sāṣṭrīya Pañcāṅga Mīmāṃsā,* 69-96. The inadequacies of empirical sinusoidal corrections are discussed in detail.

18 The annular solar eclipse in Kurukṣetra on 21st August 1933 (Vikrama Samvat, 1990) had appreciable error as given in *Pañcāṅgas* based on *Sūrya-siddhānta.* At that time the *Mārtaṇḍa Pañcāṅga* (by Pt. Mukunda Vallabha Jyotisacarya at Kurali, Ropar, Punjab), based on accurate data was successful in predicting the timings of the solar eclipse most correctly, which attracted the attention of the common masses at that time (see *Mārtaṇḍa Pañcāṅga,* V. 1990).

19 *Bījopanaya* is really due to Bhāskarācārya. It is varified by the author using the results from very accurate computer programmes for Śaka 1036, the year of observation by Bhāskara II and analyzing, the lunar position for equations of centre. T. S. Kuppanna Sastry in one of his papers conjectures this to be a forgery on the basis of the fact that Bhāskara made a mistake in formulating the method, but Sastry over-looked the fact that with the type of *Golayantra* used by Bhāskara and without Fourier analysis like methods errors were expected. Such mistakes were committed by many astronomers up to the 18th century A.D.

20 *Jyotirgaṇitam, Mārāthī Grahagaṇitam,* and *Bhūmaṇḍalīya Sūryagrahaṇa Gaṇitam* by V. B. Ketakara.

21 'Mathematical analysis of post-Vedāṅga pre-siddhāntic data etc." Ph.D. thesis of S. S. Lishk, 121, 175. See also *Jambū-dvīpa prajñapti,* 7-2 and *Sūryaprajñapti, Prābhṛta* 18.

22 Sharma and Lishk, 'Latitude of Moon in Jaina Astronomy', 28-35.

23 Pingree and Neugebauer (ed) *Pañcasiddhāntikā,* III, 31, The verse gives Moon's latitude as 280'= $4^\circ\ 40'$; but usually the value $4^\circ\ 30'$ is adopted.

24 Satya Prakash, 584.

25 Bose, Sen and Subbarayappa (eds), *A Concise History of Science in India.*

26 Madhya-lagna-same bhānau harijasya na sambhavaḥ/
Akṣodāṅ-madhyabha-krāntisāmye nāvanaterapi//
(*Sūrya-siddhānta,* ch. on solar eclipse, *śl.* 1

It means: *Harija* (meaning parallax or horizontal parallax in loose terminology) does not exist when the Sun is at the position of *madhya-lagna* and the *avanati* (or *nati,* the parallax correction in latitude) does not exist when north declination of *madhya-lagna* equals the geographical latitude of the place.

27 Āryabhaṭīya eds. Shukla and Sarma, *Golapāda Kārikā,* 33-34, pp. 145-147.

28 Reference 27, p. 146.

29 *Mahābhāskarīyam,* ed. Kuppanna Sastry, Introduction, XVII; K. S. Shukla gives the date as A.D. 629 (*Gaṇita* V, i, *śloka* 27).

30 *Brāhmasphuṭa-siddhānta,* ed. Ram Swarup Sharma, Vol. 1, 144, *śl.* 27.

31 *Āryabhaṭīya,* ed. K. V. Sarma (1976).

32 Reference 30, Introduction in English by Satya Prakash.

33 Srivastava, *Sūrya-siddhānta, Vijñāna Bhāṣya,* 590.

34 *Makaranda-sāriṇī* ed. Ganagadhara Tandon, 166.

35 Kamalakara Bhaṭṭa's *Siddhānta-tattvaviveka,* solar eclipse to *mahāpraśna;* commentary by Gangadhara Misra (1941).

36 Sharma and Sharma, *Śāstrīya Pāñcāṅga Mimāṃsā,* 34-38.

37 Private communication between the author and Shri Ganapati Deva Shastri, son of Sh. Bapudeva Shastri on this topic.

38 *Prapadyete śraviṣṭhādau sūryacandramasāvudak/ Sarpārdhe dakṣinārkastu nāghaśrayaṇayoḥ sadā// (Vedāṅga Jyotiṣa).* "The Sun and Moon start their journey towards north in the beginning of Śraviṣṭha (Dhaniṣṭha) in the month of Māgha. The Sun starts its southward journey in the middle of Āśleṣā in the months of Māgha and Śrāvaṇa". This is a naked-eye observation which belongs to 15th century B. C. The actual astronomical observations (being not extrapolated) are nore reliable than other evidences.

39 *Samavāyāṅga Sūtra,* 3; *Sthānāṅga Sūtra,* 227; *Sūryaprajñapti, prābhṛta,* 10: 9, etc.

40 Tilak, *Oriom,* 5th edition (1922), the text is so named as to indicate the fact that Mṛgaśīrṣa (Orion) headed the *nakṣatra* list at the time of remote Vedic literature.

41 *Orion,* 4th edition, 31.

42 *Śatapatha Brāhmaṇa*, 2-2-2 runs as follows:
Kṛttikāsvādadhita naita ha vai pūrvataścyanvante sarvāṇi ha vā anyāni nakṣatrāṇi pūrvataścyanvante tasmāt Kṛttikāsvādadhita. This means: "Do the *adhāna* (of fire) in (the direction of) Kṛttikās (Pleiades) because these do not deviate from east, while all other *nakṣatras* do deviate (from east)." Thus at that time Kṛttikās used to rise in the astronomical east. This phenomenon belongs to about 2700 B.C. or so, and the above statement is an old record of this event preserved in the oral tradition of Śruti. About mathematical treatment see *Śāstrīya Pañcāṅga Mīmāṃsā* and *Śāstraśuddha Pañcāṅga Nirṇaya*. Sharma and Sharma (1964).

43 *Mathematical Analysis of post-Vedāṅga*, etc., being Ph.D. Thesis of S. S. Liskh.

44 *Report of the Calendar Reform Committee* (1955), 205.

45 *Commentary on Āryabhaṭīya by Bhāskara I and Someśvara*, ed. K. S. Shukla, 183. Pṛthūdakasvāmi, in his commentary on the *Brāhmasphuta-siddhānta*, has also referred to a verse by Viṣṇucandra, which reads as follows: *tasyacātra viyad—rudra-kṛta—nandāṣṭākendavaḥ* (1894110) *ayanasya yugam proktam Brahmārka-dimataṃ Purā*/That is, 'Due to that reason (because of precession) the *ayanayuga* (number of cycles in a *kalpa*) is 1894110 revolutions. It is the opinion of Brahmā, Sūrya etc. (Note that this version of the *śloka* gives an erroneous velocity of precession.

46 Colebrooke (3).

47 Neugebauer and Pingree (ed), *Pañcasiddhāntikā*, Introduction to pt. I, II. The relevant verse quoted reads: *tasya cātra cid-rudra-......*instead of *tasya catra viyad rudra....*The former version has error in meter but the latter gives much erroneous rate of precession. It is to be pointed out that some recensions of this text do not have this verse. For example, the *Vasiṣṭha-siddhānta* edited by Vindhyeswari Prasad (Varanasi) does not have this verse.

48 *Brāhmasphuṭa-siddhānta*, ed. Ram Swarup Sharma, 11th *tantra*, *śl*, 54 which condemns the *ayana calana-nāyana-yugam ayana-vaśād*, that is, 'There is nothing like *ayana-yuga*, which results from precession'.

49 See ref. 45 and also Bhāskara I's *Mahābhāskarīya*, ed. T. S. Kuppanna Sastri, Introduction, XXV.

50 *Pañcasiddhāntikā*, III, 21.

51 *Bṛhat-saṃhitā*, III, I, 21.

52 *Sūryaprajñapti*, Malayagiri's commentary, *prābhṛta* I. *prābhṛta-prābhṛta*. 2. The *gāthā* '*salāmegaṃ cotālamṃ*' has been interpreted by the author to mean 124+20=144 subdivisions.

53 Sharma (SD). (2)

54 In the *Aitareya Brāhmaṇa*, it is said that the Sun is taken by the gods to the winter solstice position and held there for days (*virāja* of five days). At that time the sacrificial ceremonies of the year were performed.

55 Sharma and Sharma, *Śāstrīya Pañcāṅga Mīmāṃsā*, 71-72. Also see Ketakara, *Ketakī-graha-gaṇitam*.

56 *Śāstrīya Pañcāṅga Mimāṃsā*, 70-71.

57 *Sūryai-siddhānta*, *Vijñāna-bhāṣya*, 344

58 *Bhāratiya Jyotiṣa Śāstra* (Hindi), 439.

59 *Sūrya-siddhānta*, *Tripraśnādhikāra*,*śl*. 9-10.

60 Such invalidities are discussed in *Śāstrīya Pañcāṅga Mīmāṃsā* in the chapter on *ayanāṃsa* and also in *Kṣayādhimāsa vyavastha*.

61 *Sūrya-siddhānta*, *Tripraśnādhikāra*, *śl*. 10

62 See ref. 41.

63 Brennand, *Hindu Astronomy*.

64 *Sūrya-siddhānta*, commentary in Bengali by Swami Vijnanananda, Calcutta, 1909.

65 Sharma and Sharma, *Śāstrīya Pañcāṅga Mīmāṃsā*, 117-118.

66 *Śāstrīya Pañcāṅga Mimāṃsā*.

67 Confusions were there and even now exist. For a series of papers on this topic by several authors see *Astronomical Magazine*. ed. B. V. Raman, Bangalore, 1960; but it is still an unsolved problem.

68 *Bhāskarīya Jyotiṣa Śāstra* (Hindi), 44. See also comments by Sharma and Sharma, *Śāstrīya Pañcāṅga Mimāṃsā*, 99.

69 S. D. Sharma on *Rājamṛgāṅka* in the seminar on the works of Bhoja, Vikrama University in 1982.

70 The Report of Calendar Reform Committee (1955).

71 Ketakara, *Jyotirgaṇitam* (Sanskrit) and *Graha-gaṇit-mālā* (Marathi).

72 Pt. Munda Vallabha Jyotisacarya, founder editor of *Mārtaṇḍa Pañcāṅga,* (Roper) saw a copy of *Raivata pakṣiya jyotirgaṇita* in press and noted down the *śloka* which was printed at that time and deleted later.

73 This was the suggestion given by the author in meeting with late N. C. Lahiri, member of the Calendar Reform Committee.

8. PHASES OF THE MOON, RISING AND SETTING OF PLANETS AND STARS AND THEIR CONJUNCTIONS

1 *Adhyāya* 18, *mantra* 40: *suṣumṇaḥ sūryaraśmiścandramā gandharvaḥ.*
2 *VG,* iv. 23.
3 *VG,* iv. 25.
4 *VG,* iv. 24.
5 *VSI,* VII, i. 51.
6 *VSi,* VII, i. 49 (c-d).
7 *KK,* Part I, vii. 4 (a-b).
8 *MBh,* vi. 5 (c-d)-7. Also see *LBh,* vi. 6-7.
9 *BrSpSi,* vii. 11-13 (a-b).
20 *VSi,* VII, i. 23-24.
11 *Siśe,* x. 16-19 (a-b).
12 *ŚiDVṛ,* X ix. 13, 14.
13 Bhāskara II's commentary on *ŚiDVṛ,* ix. 14.
14 *MSi,* vii. 7.
15 See *SiŚi,* I, ix. 7. com.
16 x. 9.
17 *SiŚi,* I, ix. 6; also his com. on it.
18 *Ibid.*
19 *Gaṇitayuktayaḥ,* Tract no. 8, p. 49.
20 *LMā,* viii. 3.
21 *GLā,* xii, 3d.
22 *LBh,* vi. 12-17, Also see *MBh,* vi. 13-17.
23 *SūSi,* x. 10-14.
24 *ŚiDVṛ,* ix. 15-19 (a-b).
25 *SiŚi.* I, ix. 10-12.
26 *GL* xii. 4.
27 *Ā* iv. 36.
28 *Ā,* iv. 35.
29 *ŚiDVṛ,* viii 3 (a-b).
30 *VSi,* VII, i. 9.
31 *SiŚe,* ix. 4.
32 *BrSpSi,* vi. 3; also xxi. 66; x. 17.
33 vii. 2, 3.
34 *SiŚe,* ix. 6.
35 *Siśi,* I, vii. 4; vii. 5 (a-b).
36 *LBh,* iii. 7-9.
37 *LBh,* ii. 11.
38 *LBh,* iii. 16.
39 *BrSpSi,* iii. 64 (a-b).
40 *LBh,* vi. 8-12 (a-b).
41 *BrSpSi,* vi. 2.
42 *SūSi,* ix. 2-3.
43 *VSi,* VI, 1-2.
44 *ŚiDVṛ,* viii, 1,

[45] *MSi*, ix. 1-2.
[46] *SiŚe*, ix, 2-3.
[47] *SiŚi*, I, viii. 4 (c-d)-5.
[48] *Ā*, iv. 4.
[49] Part I, vi. 1.
[50] *BrSpSi*, vi. 6. 11, 12.
[51] *ŚiDVṛ*, viii. 5.
[52] *VSi*, VI. 3.
[53] *SiŚe*, ix. 8-3
[54] *MSi*, ix. 3.
[55] *SiŚi*, I, viii. 6.
[56] x. 1; ix. 6-8.
[57] *BrSpSi*, vi. 11, 12; *KK*, II, v. 3-4.
[58] ix. 7.
[59] *SiŚe*, ix. 9.
[60] *LBh*. vii. 3.
[61] *ŚiDVṛ*, viii. 5 (c-d)-8.
[62] What is meant is that, in the case of rising or setting in the West, one should compute for sunset the longitude of the planet and apply to it the visibility correction of setting and also the longitude of the Sun. Both of these should be increased by six signs. One should then find the *asus* of rising of the traversed part of the sign occupied by the resulting planet as also the *asus* of rising of the untraversed part of the sign occupied by the resulting Sun.
[63] *VSi*, VI. 23 (b-d)-25, 27.
[64] See e.g. *BrSpSi*, x. 32; vi. 7;x. 33; *SūSi*, ix. 16; *MSi*, ix. 4-5; *SiŚe*, ix. 12-13; 10; *SiŚi*, I,viii. 8 (c-d)-10.
[65] *KK*, II, v. 8-10.
[66] *ŚiDVṛ*, xi. 16-17, Also see *SiŚe*, xii. 16-17.
[67] *VSi*, VIII. 19 (c-d)-20.
[68] *SiŚi*, I. xi. 12-14.
[69] *BrSpSi*, x. 39; *KK*, II, v. 12.
[70] *ŚiDVṛ*, xi. 18-19.
[71] *SiŚe*, xii. 18.
[72] *VSi*, VIII, ii. 21 (a-b).
[73] *SūŚi*, ix. 18.
[34] *BrSpSi*, x. 38 (c-d); *KK*. II, v. 11 (c-d).
[75] *SiDVṛ*, xi. 20 (a-b).
[76] *VSi*, VIII, ii. 21 (c-d); *SiŚe*, xi. 21 (a-b); *SiŚi*, I, xi. 15.
[77] *MBh*, vi. 27.
[78] *MBh*, vi. 28.
[79] *MBh*, vi. 35.
[80] *MBh*, vi. 32-33.
[81] *MBh*, vi. 37-38.
[82] *VSi*, VII, 1. 2-5.
[83] LBh, vi. 20-21.
[84] *ŚiDVṛ*, viii. 9-10.
[85] *VSi*, VII, 1. 7-8.
[86] *BrSpSi*, ii. 60; *KK*, I, iii. 3.
[87] *ŚiDVṛ*, ii. 20 (c-d)-21.
[88] *SiŚe*, iii. 70.
[89] *SiŚi*, I, ii. 52.
[90] *VSi*, VII, i. 11.
[91] *MSi*, x. 4-5.
[92] *MSi*, x. 8.
[93] *SiŚi*, I, xi. 16.
[94] *KK*, I, viii. 1 (Bhaṭṭotpala's com.).
KK, I, viii. I,

96 *SūSi*, vii. 1.
97 *SūSi*, vii. 23 (a-b).
98 *SūSi*, vii. 18-19.
99 *SūSi*, vii. 20 (c-d)-23 (a-b).
100 Quoted by Kapileśvara Chaudhary in his com. on *SūSi*, vii. 18-19.
101 *MBh*, vii. 49-51.
102 *LBh*, vii. 6-10.
103 *KK*, I, viii. 3-6 (a-b).
104 *VSi*, VIII, i. 7-8.
105 The vitribha or vitribhalagna is the lagna ("rising point of the ecliptic") minus tribha ("three signs").
106 *KK*, I, viii. 5-6, com.
107 *SiŚi*, I, x. 7-9, com.
108 For, the planet whose rising point at rising and the rising point at setting are both smaller than of the other planet, has greater day-length than the other. So the latter is swifter than the other.
109 *BrSpSi*, ix. 13-18.
110 *SiŚe*, xi. 21-27.
111 (15).
112 These are the *ghaṭis* elapsed since or to elapse before conjunction along the circle of position, at the time of conjunction, chosen by conjecture.
113 *BrSpSi*, ix. 22-25; *KK*, II, vi. 1-4.
114 *ŚiDVṛ*, x. 17-20.
115 *SiŚe*, xi. 28-31.
116 *BrSpSi*, x. 51-56.
117 *VSi*, VIII, i. 12-14.
118 *MSi*, xi. 3 (c-d)-6 (a-b).
119 vii. 7-12.
120 VIII, i. 9.
121 *SiTVi*, *Bhagrahayuti*, vss. 105-106.
122 *SiŚi*, I, x. 4 (c-d)-5, gloss.
123 *SiŚi*, I. x. 3-5.
124 The junction stars are the prominent stars of the *nakṣatras*.
125 *LBh*, viii. 5.
126 *MBh*, iii. 71 (a-b).
127 *KK*, I, ix. 7.
128 *ŚiDVṛ*, xi. 4.
129 *VSi*, VIII, ii. 4 (a-c).
130 *MSi*, xii. 9.
131 *SiŚe*, xii. 3.
132 *SūSi*, viii. 15.
133 *KK*, I, ix. 14. Also see *BrSpSi*, x. 4.
134 β or δ Scorpii.
135 α or K Librae.
136 *MBh*, iii. 71 (c-d)-75 (a-b). Also see *LBh*, viii. 11-16.
137 *SūSi*, viii. 13 also.
138 *BrSpSi*, x. 11-12; *KK*, ix. 15-16.
139 *ŚiDVṛ*, xi. 11.
140 *VSi*, VIII, ii. 10-11
141 *SiŚe*, vii. 8-9.

9. INDIAN CALENDAR FROM POST-VEDIC PERIOD TO A.D. 1900

1 This number is according to the book *Vedāṅga Jyotiṣa* published in Bengali by Sanskrit College, Calcutta. According to Balkrishna Dikshit, vide *Bhāratīya Jyotiṣa Śāstra*—Part I (English Translation), this number is 43.

2 According to S. B. Dikshit, this number is 49.

3 Calendar Reform Committee's Report, page 222.

4 RCRC, 225; Dikshit (4), Eng. trans., Part, I, 92. Part I, 92.

5 Dikshit (4), Eng. trans., Part I, 92; RCRC, 223. 2nd column.

6 Dikshit (4), Eng. trans. part I, 91; RCRC, 225.

7 RCRC, 225, and Dikshit (4), Part I, 90.

8 One day was added as required to conform to the position that the 1st day of the *yuga* starts with *Śukla pratipada* day of the month of Māgha as explained before.

9 *VJ* (yajus),—verse 16, 38, 39 and 40; and *VJ* (ṚK), verse 14, 25, 26 and 27.

10 P. C. Sengupta's Introduction to Burgess's *Sūrya siddhānta*, XXXIV.

11 *A Concise History of Science in India*, 81.

12 P. C. Sen Gupta's Introduction to Burgess's *Sūrya-siddhānta*, xii.

13 Introduction to Burgess's *Sūrya-siddhānta* by P. C. Sengupta, XII (Reprinted edition 1977 by Indological Book House). Dikshit's *Bhāratīya Jyotiṣa Śāstra*, Part II, 23, 27 and 53.
Burgess's *Surya-siddhānta*, 22, 27 and 28.

14 *Indian Astronomical Ephemeris*—1983, 477.

15 Dikshit, (4), Part II, 66; *RCRC*, 240.

16 Dikshit (4), part II, 12.

17 (a) Burgess's *Sūrya-siddhānta*, 19; (b) Sengupta's Introduction: IX, XIII, (c) Dikshit (4), part II, 44 (English Translation)

18 *Introduction to Indian Ephemeris & Nautical Almanac*, 1958, Part XII.
Sen Gupta's Introduction to Burgess's *Sūrya-siddhānta*, XLVI, XLVII.

19 With *bīja* correction.

20 (i) *General Astronomy* by Sir Harold Spences Jones, Chapter VI; The Moon.
(ii) *Introduction to the Indian Ephemeris & Nautical Almanac for* 1958 (1st issue).
(iii) *The Moon*, edited by A. V. Markov, University of Chicago Press.

21 RCRC, 169; Burgess's *Sūrya-siddhānta*, note to verse 52, chapter I.

22 (a) Science and Culture: Sept 1952, 115; (b) RCRC Report; 169. (c) Burgess's *Sūrya-siddhānta*, note to verses 51 & 52; p. 36.

23 Explanatory Supplement to the *Astronomical Ephemeris & Nautical Almanac* (1961), Chapter on Calendars, p. 419.

24 Dikshit (4), Part II, 277; RCRC, 171.

25 *Sūrya-siddhānta*, ch. II, verse 66; Burgess's note, p. 106.

26 Quoted from *Gupta Press Pañjikā* of Calcutta.

27 Quoted from *Biśuddha Siddhānta Pañjikā* of Calcutta.

28 RCRC, 184 (changed to nirayana system).

29 Dikshit, (4), Part II, 278, 279.

30 Dikshit (4), Part II, 275, Note.

31 RCRC, 193.

32 Dikshit (4) Part II, 273; *RCRC*, 244.

33 Chatterjee, (3), 10.

34 Explanatory Supplement to the *Astronomical Ephemeris and Nautical Almanac* issued by H. M. Nautical Office 1961, 439.

35 Chatterjee, (3), 12.

36 Author's Paper 'Year—beginning through the Ages' published by the Indian Standards Institution in their bulletin, August 1977.

37 (a) *Calendar of Middle East Countries* by V. V. Tsybulsky U.S.S.R. Academy of Sciences, pages 8 & 9.
(b) 'Explanatory Supplement to Astronomical Ephemeris and Nautical Almanac' (H. M. Nautical Office), page 411.

38 *Ancient India* by R. C. Majumdar (8th Edition, 1977), 129, 236.

39 *Ancient India* by R. C. Majumdar (8th Edition, 1977), 123.
40 *RCRC*, 258, Table 27.
41 *Advanced History of India* by R. C. Majumdar (4th Edition), 80, 93.
42 *Raṣṭrīya Pañcāṅga,* 1905 Saka, Page XIII.
43 *Advanced History of India* by R. C. Majumdar (4th Edition), 80, 93.
44 *Raṣṭrīya Pañcāṅga,* 1905 Śaka, III.
45 *RCRC*, 257.
46 *Bhāratīya Jyotiṣ Śāstra, Part II,* 258; *Ākbar Nāmā,* Vol II, by Beveridge, 32; Cunnighham's *Indian Eras,* page 225.
47 *Calendars of the Middle East countries,* U.S.S.R. Academy of Sciences, Institute of Oriental Studies, 88.
48 *Ākbar Nāmā,* Vol II, 15.
49 *Ākbar Nāmā,* 17.
50 *Ākbār Nāmā,* Vol. III, 644.
51 (a) *Tārikh-i-Ilāhi* by V. S. Bendrey, (Poona, p. 14). (b) *Akbar the Great Moghul* by Vincient A Smith, Appendix C p. 326.
(c) *Ākbar Nāmā,* Part II, Chapter III, 16, 17 (Note).
52 *Tārikhi-i-Ilāhi; Ākbarnāma*—Vol. II, 16, 17.
53 *Ākbar Nāmā* Vol II, Chapter III, page 17 (Note). (*Ākbar Nāma* Vol II, Chapter III, page 22).
54 (Dikshit's *B.J.S.* Part II, page 258).

11. ASTRONOMICAL OBSERVATORIES

1 *Sūrya-prajñapti, Prābhṛta* 9, gives elapsed time of the day in units of *puruṣas.*
2 *Sūrya-prajñapti* (S. P.) (*Prabhṛta* 1, *Prabhṛta—prabhṛta*-2) gives details of these experiments for daily observations of rising of Sun and thus determining length of the solar year. *Kātiya Śulba-sūtra* and *Jyoitsakarandaka* too mention such experiments (Details in S. P. will occur in commentary on the same by S. D. Sharma).
3 Earliest gnomonic experiments in Indian astronomical traditions are indicated in *Aitareya-Brāhmana* (P. C. Sengupta in *Ancient Indian Chronology*). Also refer to Appendix 5-C of Report of Calendar Reform Committee, Government of India (1955). *Sūrya-siddhānta in grahayutyadhirāla* (Slokas 15-17) mentions use of two gnomons, thread & mirror.
4 *Vedāṅga-jyotiṣa* mentions the amount of water to be added everyday to compensate for day light.
5 It is interesting to note that *Jyotiṣakarandaka,* a prākṛta text, gives details of water equivalent to a *muhūrta* and it gives minutest details for preparing a balance for weighing water.
6 Gnomonic experiments on Moon's shadow are reported in the first few *Ślokas* of *Atharva Vedāṅga-Jyotiṣa.*
7 Mathur.
8 *Sūrya-siddhānta, Bhūgolādhyāya,* with Vijñana-bhāṣya by Mahāvira Prasad Srivastava.
9 The word *"nara"* got used for gnomon (vertical stick) because this evolved from observations of shadow of man *(nara)* himself.
10 *Śārdūla karaṇāvadāna* mentions use of 7 *aṅgulas* gnomon, but in all other astronomical works 12 *aṅgulas śaṅku* (gnomon) got into use.
11 *Siddhānta-śiromaṇi, Yantrādhyaya.*
12 *Bhāratīya Jyotiṣa* by Shankara Bala Krishna Dixit, translated in Hindi by Sivanath Jhārkhandi 1963, pp. 457.
13 It may be pointed out that some scholars like Kuppanna Śastri think this text to be a forgery on the basis of the fact that this has some error. but the author has proved in his "Śāstriya Pañcāṅga mīmānsā that this text too belongs to Bhāskarāc'ārya. In fact Bhāskarāc'ārya was confused because of lack of Fourier like analyses of sinusoidal functions. Bhāskarāc'ārya got 6-20′ as equation of centre but missed evection as he performed experiments at points where evection was zero but was able to find annual variation. His correction without Muñjal's made eclipses more erroneous. Had he used Munjal's correction, he would have not been confused. The simultaneous use of his correction and Muñjal's would have improved the prediction of eclipses to a better degree of accuracy.

[14] *Jyotiṣkaraṇḍaka* gives details of constructing Water clock starting from melting iron and shaping to form the pot of required shape and then piercing a hole in it.

[15] *Siddhānta-śiromaṇi* of Bhaskarācārya, *Yantrādhyāya*, ślokas 48-49.

[16] *Sūrya-siddhānta* has technique of observing planets in water. *Graha-yutyadhikāra, ślokas* 15-20 and in all other standard treatises too we have similar practical methods. Kamalākara in his *Siddhānta-tattva-viveka* has discussed phenomenon of reflection of light in much details on physical grounds. It may be remarked that law of equality of angles of incidence and reflection was utilised in the practical methods in the sense that the equal *bhuja* and *koṭi* for the planet and its image were taken with the sign of *bhuja* (x-coordinate) changed.

[17] Sharma (S D) (3). In one of the manuscripts procured by the author, it is mentioned "the details of the Pratodayantra designed by Gaṇeśa end here in chapter on instruments in *Siddhānta-sārvabhauma* which shows that this instrument was invented by Ganes' a Daivaiña and included by Munīshvara in his treatise.

[18] Paṇḍitashram of Srāvana V. 1959 (1902 A.D.)

[19] *Sūrya-siddhānta, yutyadhikāra, ślokas* 15-17.

[20] *"Atharva Vedāṅga-Jyotiṣa"*published by Pitmbara Peetha. The *ślokas* in the beginning of this text define *muhūrtas* during night on the basis of Moon's shadow (probably on Pūrṇimā day).

[21] Dikshit (4), Hindi trans., p. 355.

[22] Mathur, 'Origin of Observatories in India'.

[23] Bhāvan, A guide to observatories in India (in Hindi).

[24] Kaye (4), 9-10.

[25] Hunter (3), 177 ff. Also see chapter 11 by Ansari.

[26] Mathur, 'Origin of Observatories in India'

[27] See Kaye (8)

[28] Kaye (4) Ch. V on "Hindu Metal Instruments", pp. 31-34.

[29] See Sedillot's *prolegomenes des tables astronomiques d'ouloug Beg,* P. C XXXIX.

[30] Preface in *Zij--i-Mohammad Shāhi.* Available in Sanskrit and Persian versions. See also "Jai Singh and his Zij-i-Muhammad Shahi" paper by Vīrendra Sharma, presented in Conference of South Asian Studies, University of Wisconsin, Oct. 1979. The above extract is from a paper by Hunter, *Asiatic Researches*, 5 (1799).

[31] Sir Robert Barker left India in 1773 A.D. Mr Champbell, Chief Engineer of East India Company, prepared detailed drawings for him in 1772-73. The Observatory was built in 1737.

[32] Śāstri, Bāpudeva, *Kāshi Mānā mandira Vedhālaya Larnanam.*

[33] Kaye, 61-68. A guide to Observatories in India, Bhāvan.

[34] Kaye (4), 61-66.

[35] Sastrī, Bāpudeva, 22 ff.

[36] See ref. 35, pp. 34-35.

[37] Sastrī, Bāpudeva, Manā-Mandira Observatory.

[38] For details, see Ref. 35, pp. 26-27.

[39] British Museum papers of right honourable Warren Hastings the 1st Governor General of Bengal, 1745-85 (See also ref. 35, Introduction, p-5).

[40] Kaye (8), 34.

[41] Gurjar, *Ancient Indian Mathematics and Vedha.*

[42] Kaye (8).

[43] Gurjar, 186-87.

[44] "Stone Observatories of India" by Prahlad Singh (Bhārata Maniṣā, D28/171 Pande Haveli Vārāṇasi), pp. 168-169.

[45] Refer 44, 192.

[46] Garret, Guleri and Chandradhar.

[47] This value of obliquity was found by Sawai Jai Singh.

[48] *Yantra-rāja* of Mahendra Sūri with commentary by Malayendu Sūri, edited by Krishna Shanker Keshava Ram Racqua, Niranaya Sagar Press, Bombay (1936).

[49] "Stereographic projections" by B.A. Rosenfield & N. D. Sergeva, Translation from Russian by Vitaly Kisin M.I.R. Publication, Moscow (1977).

[50] Refer 41, pp 191-197.

51 Some of the more relevant texts in Sanskrit are: (a) *Yantra-rāja-ghaṭanā* by Mathurānāth (Around A.D. 1813) (b) *Yantra-rāja Ṭīkā* by Yajñeswara (1842 A.D.); (c) *Yantra-rāja Vāsanā* by Yajnes'wara (1842 A.D.). (d) *Yantra-rājopayogi Chhedyaka* by Bāpudeva Śastri (19th A.D.); (e) *Yantra-rāja Rac'anā* and also Vedhavidhi" under the supervision of Sawai Jai Singh, published by Rajasthan-purā-tattva Mandira Jaipur (1965); (f) *Yantra-prabhā* by Shrīnāth Chhagani; (g) *Yantra-rāja prabhā* edited by Pt. Kedāra Nāth Jyotirvid.

52 "Yantra Rāj' by Mahendra Sūri with commentary by Malayendu Sūri (in Sanskrit) edited by Sh. Krishna Shankar Keshava Rama Racqua (1936); pp. 5. This edition has 'yantra-S'iromaṇi" of Sh. Viśrāma also.

53 Asiatic Researches, 1790, Vol. II, p. 489.

54 Kaye (8).

55 Refer 45. pp. 208-209.

12. INTRODUCTION OF MODERN WESTERN ASTRONOMY IN INDIA DURING 1800-1900 CENTURIES

1 Balfour, Vol. 1, P. 194—195.

2 In Sanskrit it is *Vedāṅga Jyotiṣa*. See for an account, Chap. I, Sec. II of Dikshit (4) (English translation).

3 RCRC Chap. V, 212-222.

4 Varāhamihira, *Pañcasiddhāntia*.

5 Shukla, *Sūrya-siddhānta*, see also Burgess.

6 Pingree (5), (16).

7 See Billard, who proves this point by statistically analyzing the Indian date.

8 See Shukla (1), note his excellent account of Hindu planetary theory in Chap. IV. This bigger work of Bhāskara I was composed by him in 7th century. He was a follower of Āryabhaṭa I and a contemporary of Brahmagupta, see the also relevant chapters in this volume.

9 According to E. B. (Vol. 16, p. 828) an observatory is defined as "a special building for astronomical research". However we think that observatories should be defined as *institutions of organised astronomical observations* done by a team in contrast to places where such work is done by individuals; the latter existed in ancient India, as is apparent from the work of various Indian astronomers who flourished between 5—12 A.D., see Billard.

10 Sayili, P 358, also Ansari (6).

11 Kaye, von Kluber, Blanpied, also Bose et al (Chap. 2, p. 126), Garret.

12 Sobirov, esp. p. 92—102.

13 Niyazov; see also ZMS, f. 2a.

14 Ansari (5), P. 165; Ansari and Ghori (a).

15 For first report see Ansari (4) esp. p. 63; for more details see Ghori P. 55-57, also cf. Ansari and Ghori (2). See ZMS folio 81 at seq. *K̲h̲ātima, Muqāla som, fasl som.*

16 Mss. RI—53, Mulla Firoze Library, Bombay.

17 See Al-Tehrani, vol. 11, p. 88, entry No. 580.

18 In fact many terms like *Optic, glass, perspective, perspective, glass, trunke-spectacle Trunk glass* etc. were used for telescope originally. The word "telescope" was coined presumably by Prince Cesi (Head of Roman Academy of the Lincei) about 1613 but was used systematically in 1620 by the Catholic astronomer Josephus Blancanus in his treatise *Sphaera Mundi* cf. McColley.

19 cf. Qaisar, p. 34—35 also 71. Qaisar quotes especially the names of Aṣaf Khān, Govern of Bengal Shāh' Ista K̲h̲ān's son, Nawab of Patna and the Indian Merchant Rustamji who purchased it from English factors; see his footnotes No. 117—122, p. 163.

20 Cf. Tek Chand's Bahār-i 'Ajam. It is not clear to us why Sobirov assumed merely the *possibility* of the use of telescope by Jai Singh. It appears to us that Sobirov could translate the word *dūrbīn* only as "optical instrument", and not as telescope though the latter translation is found in some Indo-Persian dictionaries of 18-19th century.

21 Moraes, also MaClagen p. 133-134 and Soonawala.

[22] We do not have a definite proof, but how could then Jai Singh get constructed a telescope without owning a model.

[23] Mercier has tried to show "that all tables of the Zīj concerning Sun, Moon and planets are taken directly from La Hire's work. They in no way depend on observations made in India". This opinion is contradicted by the very first question which Jai Singh put to Father Calmette (cf. Mercier's appendix A). It dealt with the disagreement between observed Moon's longitude and the value calculated according to La Hire's tables. The discrepancy amounted to $\frac{1}{4}$ minute, cf. preface of ZMS, f. 2b. In other words, that question particularly (and others also) indicates clearly that Jai Singh's astronomers were observing and also that they were not following the Frenchman's tables blindly. In fact, the questions were posed especially to understand the underlying geometrical model of La Hire; see also Ansari & Ghori (b).

It may be added that only a very badly transcript of La Hire's tables from the edition of 1727 is extant in Jai Singh's Library at Jaipur. It was presented to him by Joseph Du Boio on Sept. 10, 1732. The 3—volumes tables of Joh. Flemsteed: *Histo Coeıostis Britannica*, London (1675-1689) were acquired probably later.

[24] For the first report on the diagrams see Ansari (c).

[25] Cf. also Volodarsky, P. 190. He defines it as the early prevalent opinion according to which "the totality of modern world mathematics (for example) was created exclusively by the European scholars. The role of other non-European scholars then turns out to be at the most as passive receptors of antique Greek tradition and as communicators of Hellenistic knowledge to the Medieval West Europe...." This Eurocentric view of the development of World-Science is shown to be completely false by the soviet historians of science particularly; see Volodarsky for details. In the last three decades several historians of science in West Europe have also negated the early prevalent "Euro-centris" by their work.

[26] Kaye, P. 48. Strangely enough he also quotes Khān's original book: *Āt͟har-al-Ṣanādīd,* I Edition, Delhi 1852. In this particular edition (and not in the first) Sayyid Aḥmad Khan listed the telescopic rediscoveries and Jai Singh's interaction with the Jesuits quite in details with reference to the Zīj itself; see also Ansari (4), esp. p. 63.

[27] De Tassy P. 542.

[28] Kaye, P. 48, 89, 6 and 83. Note that the first use of telescopic sights was not in 1667 but in 1634 by Jean Baptist Morin (1585-1656), see King, P. 94.

[29] Van Helden, P. 42, emphasis ours.

[30] Allen, P. 301.

[31] Van Helden, P. 55.

[32] Cf. the excellent description of Allen, also king.

[33] It has been reported that the Jesuit cartographer Boudier employed in India a telescope of 20 ft for his observations of Jupiter's satellites, see section 2.1. However in Europe Huygens, Cassini and Hevelius got constructed telescopes of 123, 136 and 140-150 feet respectively. One may imagine especially the difficulties of installation and stability problem of such huge telescopes, suspended from a mast and operated by a system of pulleys, see King for details. In contrast, Jai Singh's masonary instruments had not at all any of the above-mentioned problems.

[34] Auzout (1622-1691) reinvented the micrometer in 1666. See King Chap. IV, P. 93 seq, Repsold, P. 41-42 and also Brandt.

[35] See King P. 100. For an excellent summary of the correspondence between Hevelius and Flemsteed, consult Forbes (a), P. 34-39

[36] Quoted in King P. 100.

[37] King, P. 51, Repsold P. 36-39.

[38] Forbes (1), P. 38-39.

[39] Repsold, P. 39 and 36.

[40] Allen P. 311. Actually a parallel but more significant development was the invention reflecting telescope by Gregory (1663), Newton (1671) and Cassegra in (1672). Modern telescopes of very large light-gathering power are all reflecting ones. For telescopes installed recently in India and future Indian astronomy programmes see the article on Bhattacharya in this volume.

[41] Cf. Forbes (2) for the origin of this idea.

[42] *ZMS,* f. 46 et seq, Maqala III, Bab 1, fasl 2.

[43] In the text of ZMS, we have sought in vain for the mention of heliocentric system. The sentence, which according to Sobirov's (P. 107) translation reads: "First of all it is important to note that these orbits are of elliptical shape. In one of the centres of which the Sun exists (by the centre of the ellipse Jai Singh means its focus)", is not extant in the manuscripts of *ZMS* available to us. A somewhat similar model was also given by the Jesuit I. Kogler in his chinese treatise (ca 1742), see for Chinese parallel sec. 2.2.8, also Nakayama p. 174, Sivin p. 91-92.

[44] Schofield (1), esp. p. 295, cf. also Schofield (2), Recall the elliptical orbits of Jai Singh, mentioned above.

[45] For details, see Hartner.

[46] Dijksterhuis, p. 300.

[47] Johnson, p. 285. According to him only one text-book by Albert Lonicerus (Cologne, 1583) is recorded in contemporary bibliographies.

[48] Dijksterhuis p. 299.

[49] Cf. a parallel situation in China, sec. (5.2.2.).

[50] Johnson, esp. p. 286-289.

[51] Ansari (3) and (4).

[52] The motivation for practical astronomy was in fact inherited by Europeans from the Islamic astronomers, who were the pioneer in building observatories right from 9th to 16th centuries. The most famous observatories were at Marāghā (founded in 1259), Samarqand (1420), Istanbul (1575-77), to name a few; cf. Sayili, Ansari (7), Ansari and Ghori (1).

[53] The predecessors of European explorers/geographers were the Arabs and Chinese, for navigation in the Indian Ocean and the China Seas, see Needham (a).

[54] A Chronometer was taken by Commander James Cook during his second Voyage (1725-75), E. B. edition 1966, P. 142.

[55] E. B. edition 1932, P. 141, emphasis our.

[56] Cf. E. B. (1966), P. 832. One such atlas produced by the famous firm of Joh. Baptist Hoeman (1664-1724) was brought by the Jesuits for Maharaja Jai Singh, see sec. 1.3. above.

[57] The Knotty problem of longitude at sea could be solved satisfactorily only in early 20th century; see section 2.3.

[58] This was exactly the case in India, compare for instance the astronomical activities of Maharaja Jai Singh or for that matter of emperor Muhammad Shah (reigned 1718-48 of Nasiruddin Haidar (reigned 1827-37); see sections 1.2, 1.3, 3.3. 3.4, and 3.6.

[59] Pannekoek, P. 278. This state of affairs could not occur in India. The scientific renaissance initiated by Jai Singh in the 18th century was nipped in the bud by colonisation of our subcontinent by several European powers, cf. last concluding sec. Only in Independent India the governmental patronage has been achieved satisfactorily.

[60] The successor of the first director of the Paris observatory, Cassini (1625-1712), was La Hire. Recall that a transcript of his tables was presented to Jai Singh about 173 and astronomical tables of Flemsteed (1646—1719), the director of Royal Observatory at Greenwich, are also extant at Jai Singh's library, probably of later acquisition.

[61] See below sec. (2-3), p. 32 for La Gentil's expedition.

[62] Achromatic lenses for telescope were tried first by Chester Moor Hall of Essex (England) and satisfactorily developed by John Dolland in 1758, using combination of convax and concave lenses of crown and flint glass. That type of invention presupposes a well-developed glass industry, cf. E.B. (1966), entry "telescope".

[63] In the following century it spread to other European countries and to USA.

[64] Father Adem Schal published a treatise on telescope in Chinese in 1626, cf. Needham, Vol. III. P. 444. See also P. 445 for the anti-Copernican attitude of the French Jesuits in China.

[65] According to the German Jesuit Father Joseph Neugebauer, who wrote about 1741, in Huonder, p. 86, see the final paragraph of this section.

[66] Hastings, Vol. 8, P. 714. It may be added here that the Malabar Christians claim that apostle Thomas himself found their Church. Further, that St. Thomas met his martyrdom about 50/53 A.D. near Madras. In any case, by the third century A.D. the Syrian Orthodox Eastern Church was well-established. That Church was known to the West for the first time in 1500 by the Portuguese. cf. Balfour (London) P. 713, and E.B. (b) Vol. 15, P. 575, Vol. 14, P. 558, 657 et seq.

67 According to an estimate 1,500,000—2,500,000 missions existed in India by 1700, Hastings, Vol. 8, P. 714.

68 See MaClagen, relevant chapters.

69 Cf. MaClagen, Chapters II, III, IV & VIII.

70 Cf. Phillimore, Vol. I, P. 209, 11; for the map see plate 10 facing p. 148; also quoted therein Vol. III, P. 704. For an excellent life sketch of Monserrate see Vol. I, P. 357—358.

71 Phillimore, Vol. I, P. 11, 169, 238.

72 *Ibid*, P. 238—239. The French geographer Jean—Baptiste Bourguignon d'Anville famous for his map of India, published in 1752, ibid, p. 210.

73 Cf. Rao *et al* for details. The authors are of the view that Richaud was first to use a telescope on Indian soil.

74 Cf. Noti P. 93. For details of these observations, see *Lettres*, Vol. XV (1781) P. 3 seq., new edition Vol. XV (1810) P. 269-290, in which only 60 Indian cities are listed whereas Father Tieffenthaler (Vol. II, P. 136 & 201) lists under his name a table only 22 cities.

75 *Lettres*, XV (1810), P. 279—288.

76 *Ibid*, P. 273, 288, see also Sharma.

77 *Ibid*, P. 284-85. See also Mercier for a detailed account of aperture gnomon, P. 161 and 171. Mercier tabulates and discusses also on p. 165, Boudier's observations of zenith distance of the lower limb of the Sun; see also Sharma.

78 See Gaubil's *Correspondence* with Delisle (of Royal Academy of Sciences at Paris No. 142 (July 1734), p. 372. Father Gaubil is especially famous for his treatise on the Chinese astronomy, published for the first time at Paris in 1732. A copy of this treatise is extant at Jai Singh's Library at City Palace, Jaipur. Father Antonio Gaubil (1689—1759) was an astronomer by training. He worked under Cas at the Paris observatory and corresponded actively with well-known European Sciences and also with Royal Society, cf. Needham, Vol. 3, p. 182. Needham cites in his bibliography his twelve works.

79 Gaubil to Delisle, dated Peking 18 Nov. 1751, English translation published in *Philosophical Transaction*, P. 313—318 (1753), see also Gaubil's Correspondence, 254, P. 654—656; the same opinion in ibid, No. 225 of 30 Nov. 1748, p. 585.

80 Ibid, No. 225 of 30 Nov. 1748, p. 585.

81 As late as 1793 Rennel used Boudier's values for the geographical coordinates and also his survey and his general map of Bengal of 1774; Phillimore, Vol. I, p. 314.

82 Quoted by Phillimore, Vol. I, p. 314.

83 Gracias, p. 193. See also Moraes p. 62, where he also refers to the researches Copernicus, Brahe, Kepler, Galileo and Newton. These researches are, however, not mentioned in the original reference cited by him.

84 Cf. Gracias P. 199, Noti P. 91 and 92. We have checked at the City Palace Library at Jaipur, where no printed version of La Hire's table exists, only a manuscript transcribed by Joseph Du Boio from the edition of 1727 is extant there. It is dated Sept. 10, 1732. For details of Jai Singh's embassy refer to Moraes, Soona and Maclagen P. 133—134.

85 Cf. Periera, No. 24, p. 38, No. 25, p. 38-39, Gracias p. 193—195.

86 Anton Gabelsberger of Mainburg (Germany) came to India in 1736 and in 1738 accompanied Strobel (see below) to Jaipur where he died in 1741. Nothing is known about his academic activities, cf. Huonder p. 175; Noti p. 95, footnote 1.

87 Andreas Strobel of Schwandorf (Germany) came to India in 1736 and accompanied Gabelsberger to Jaipur. After the death of Jai Singh in 1743 he went to Agra, according to 1745 Huonder (P. 179) he was received with honour by the Mughal emperor who appreciated highly Strobel's knowledge in Mathematics, astronomy, Mechanics and gnomonics. However in none of his four letters to his brother we find any specific mention regarding his academic activity. It is not clear how Noti (P. 98) claims that Strobel assisted in the translation of Napier's logarithm-tables and a work on conic-section into Sanskrit.

88 Phillimore Vol I, p. 86, see also *Lettres*, 12 (Paris 1843) p. 610—611 and Merc p. 159.

89 Noti (p. 95) gives the year of his death as 1785. However, Huonder gives 1770 according to Mullbauer's *Geschichte der katholichen Mission in Ostindie* p. 287. It appears to us that 1785 is the correct date,

see biographical sketch by Phillimore I, P. 388. Tieffenthaler was born in Bolzano (Tyrol) and had been a professor of humanities; Huonder p. 179, Maclagen p. 137.

90 His surveys was used by Rennel for his *Map of Hindoostan* (edition 1788) and by Thomas Call for his Atlas of India, see Phillimore Vol. I, 12.

91 Cf. Tieffenthaler, Vol. I, p. 26-27, 366-67. See also Phillimore, Vol. I, p.

92 Tieffenthalar, Vol. I, p. 366-367.

93 Ibid, P. 5, 222. But nowhere he mentioned the use of telescope, without which he could not have observed the eclipses of Jupiter's satellite.

94 *Ibid*, Vol. I, P. 88, 143, 163, 223, Vol. II, P. 246. The observatory at Mathura is no longer extant and Tieffenthaler's account of it is indeed unique.

95 Cf. Tieffenthaler, Vol. II, Part 1, P. 54. In fact, he knew Persian quite well and quoted, for instance, from the *Tadhkira as-ṣalāṭīn* (History of Kings); ibid. Vol. I, P. 55.

96 Phillimore, Vol. I, p. 388.

97 According to Needham, "he was the seventh member of Cesi Academy, having being elected after Galileo (Needham, Vol. III, p. 444).

98 Schall was the *first* director of Chinese Astronomical Bureau from 1645-66.

99 Verbiest was Schall's successor as a director, during 1669-1688. In 1673-74 he set up Tychonian type ecliptic armillary sphere, (ibid, p. 352.).

10' He was the director of the Bureau (1720-46), and built a Chinese type equatorial armillary sphere in 1744, ibid, p. 352. His observations of the eclipses were used even in Europe, Huonder, p. 88.

101 Director of the Bureau (1746-74). He did also excellent work on the Satellites Jupiter and compiled "all the astronomical observations carried out by Jesuits during 1717-1752", Huonder, p. 89.

102 Clavius (d. 1612) was the leading astronomer of the ecclesiastical commission for the reform of the Calender. He confirmed the telescopic discoveries of Galileo. Rannekoek P. 220.

103 Needham Vol. III, p. 444, also footnote (d).

104 He was present at the reception of Galileo, when Claviu welcomed Galileo at the Roman College after confirming Galileo's telescopic discoveries, *ibid* p. 444, footnote (a).

105 Needham Vol. III, p. 448. As mentioned before Gaubil had also his astronomical training by Cassini at Paris observatory.

106 We give only the equivalent titles in English, for Chinese titles refer to the original source.

107 According to Nakayama (p. 84), Ricci's other collaborators were Emmanuel Dia and two Chinese students of Ricci (for his other works see p. 96, footnote 2).

108 Sivin p. 76, Needham III, p. 447.

109 Needham III, p. 445, Sivin p, 76.

110 Needham III, p. 445, Sivin (p. 80-81) gives quite a bit of details of this work.

111 Nakayama P. 171, also footnote 107.

112 P. 11, footnote 3.

113 Sivin P. 91-92; also Nakayama p. 174; emphasis ours.

114 That is, inspite of a multitude of treatises in Chinese on Western exact sciences.

115 Sivin P. 91-92. Recall here Jai Singh's model of planetary motion, as given in his *Zij*, section 1.3.2, P. 11.

116 An enormous amount of literature (based upon original sources) on the introduction of the Western Science/astronomy in China as well as in Japan is available today, see Needham, Sivin and Nakayama. On the contrary almost no work of comparable size and standard has been done for India. There is no dearth of Jesuit sources in French, German and Portuguese; see also Mercier.

117 According to O'Malley the Indian Muslim mind was quite receptive to learning. He quotes Bernier who was commissioned by the then Governor of Delhi, Dānishman K͟hān for the above-mentioned venture; O'Malley, p. 16 & 390.

118 Note that the *Society for Promoting Christian Knowledge* was founded in India already in 1698, see N.N. Law, *Promotion of Learning in India* (Longmans, 191 p. 17).

119 Needham, Vol. III P. 457, see also his section 20 (3): 'Western' Science or 'New' Science, for details.

120 Already in 1597, a Church was established in Lahore, see Bhattacharyya, P. 5, (Chapter 39), see also Stocklein, Letter No. 595 (1735) from Father Figuiere in which he describes the various missions in Mughal India.

[121] He wrote *World Map with Illustrated Explications,* for the Chinese Emperor. His manuscript was in circulation among the Chinese astronomers up to 1799, it was printed in 1802-1803, Sivin P. 94 et seq.

[122] See the Concluding Section, for details.

[123] EICo took control of Awadh already in 1801, and when Maharaja Ranjit Singh died in 1839 it succeeded in expanding its authority to Punjab by 1846. After suppressing the first Indian Revolution of 1857, the Company was the sole political authority in India whence its power was transferred to the British Crown.

[124] Cf. Phillimore, Vol. I, p. 369 et seq., for an excellent biographical sketch of Rennel. In 1759 he came into the service of EICo and was appointed the Surveyor General in 1767.

[125] *Ibid,* p. 148. Rennel compiled a map of Bengal (1760-77) and by 1782 his famous, *The Map of Hindustan,* in which he used also the geographical observations of Boudier, Tieffenthaler, Grubner and of many engineers/surveyors of EICo.

[126] Phillimore Vol. I, 154. He came to India as a private tutor and was a keen astronomer, see for his biographical sketch, ibid, p. 384.

[127] *Ibid,* p. 154, 200 and 384.

[128] Cf. Phillimore Vol. I, p. 361 et seq. for biography.

[129] *Ibid,* p. 154-155. He also instructed in astronomy Robert Colebrook (1762/3—1808) who was his assistant and later Surveyor General of EICo.

[130] Though the use of time-keeper was pointed out first by Gemma Frisius in 1530, yet really good marine chronometers were invented by the Yorkshire carpenter J. Harrison during 1729-1760. For his fourth time-keeper he secured the British award of £10,000 (see above): For India mostly another Englishman Arnold's chronometers were supplied by the EICo, see Phillimore Vol. I, p. 202, also 155. For details of this problem see Forbes (c).

[131] Forbes (d), p. 78-79. Cf. also Phillimore Vol. I, p. 151 where the rewards are £5,000, £7,500 and £10,000.

[132] It has been reported that in 1674 the Frenchman Sieur de St. Pierre claimed to have discovered a method to determine the longitude and it was actually the assessment of that claim by J. Flamsteed and on whose advice later that King Charles II founded the Royal observatory at Greenwich in 1675, cf. Laurie p. 3-5.

[133] Cf. Forbes (4) p.82, and 149; Pannekoeck p. 284. From the observations of the transit of Mercury occuring in 1723, 1736, 1743 and 1753, the longitude difference between Paris and Greenwich was found to be 9^m 16^s. Besides, the transit observations were also used for determining the solar parallax. For example, from the transit of Venus in 1769 various observers deduced the value 8.55"-8.88", Pannekoek p. 286.

[134] The first observed transit of Venus occurred on Nov. 24, 1639 which was recorded by a student of Keplor, J. Horrocks. For a recent appraisal of his work see, Applebaum. The transit of Venus occurred in 1874 and 1882, none in this century and it is predicted for occurrence on June 8, 2004 and June 6, 2012; M.E.S.T. p. 51.

[135] Forbes (4) P. 8 and P. 119. For the criticism of the method of eclipses of Jovian satellites, see ibid p. 13. In this connection it may be noted that the British House of Common's Committee set up for the longitude problem in 1713 consulted even Sir I. Newton for his opinion; ibid p. 78.

[136] Quoted in Phillimore, Vol. I, p. 153. It is important to note here that not only the practical applications of astronomy motivated the Directors of EICo, but also the possibility of *astronomical discoveries.* However as we shall see in the following sections, Western Astronomy in India remained in the hands of EICo initially as an instrument for geography and navigation, and later subservient to the Astronomer Royal's programme. In fact *astronomy could not become a scientific discipline* (even at Indian universities) neither during the British period nor in independent India, cf. the concluding section.

[137] Court dispatch to Bengal, dated 16.3.1768, Phillimore Vol. I, p. 153.

[138] Le Gentil had been one of the assistants of Cassini (1625-1712), the Director of Paris Observatory. He published detailed accounts of his voyages in the Memoirs of the Royal Academy of Science (Paris), 1779 and 1781. Cf. Phillimore vol. I, 169, Pannekoek p. 286-287.

[139] For his biographical sketch see Phillimore Vol. I, P. 316 et seq., and for his work p. 155 et seq.,

[140] Phillimore Vol. I, P. 155-156.

[141] For instance, "of dip and variation of the compass, refraction and its variation with regard to heat, moisture....", Phillimore, Vol. I, p. 157.

[142] Ibid, p. 160.
[143] Ibid, p. 162-163.
[144] Ibid, p. 164-165.
[145] Phillimore Vol. I, p. 163.
[146] Ibid, p. 316, 156, 161, 268. He even wrote to the then Governor General Warren Histings "for the value of research in Hindu writing on astronomy, and study of Banaras Observatory" Ibid, p. 150.
[147] Robert Colebrook, the Surveyor General in 1794, took the chair from Burrow, Ibid, p. 167.
[148] Phillimore Vol. I, p. 170-172.
[149] Phillimore Vol. I, p. 172
[150] See Ansari (3) and (1), Besides those listed here, 59 meteorological observatories at various Indian cities and towns were founded by Indian Meteorological Department (established in 1875). The history of those observatories is also quite interesting but it does not lie in our purview, see for details I.M.D. (1).
[151] Love, Vol. III p. 319-321, 345 and 415, where original references to the record are given. See also Topping's own description/report.
[152] Francis, p. 373, see also Markham p. 328-346 and Phillimore, Vol. I, p. 171.
[153] Bose et al, p. 494. Note a very brief account of the astronomical work done at on p. 505-506. For the first detailed account, see Ansari (d), on which much of present account is based.
[154] Phillimore Vol. I, p. 170, for his biographical sketch see ibid p. 389-393.
[155] Here his tomb is erected, ibid, p. 389.
[156] Love. Vol. III, p. 345.
[157] Phillimore, Vol. I, p. 172.
[158] Ibid, p. 347, where original records of 1787-88 are quoted.
[159] He was a member of the Madras civil service and a keen astronomer. In 1807 he acted as Governor of Madras and Governor of PWI till his death 27-10-1816; Phillimore V. I, p. 171. According to Topping "Mr Petrie's observatory was, ..., the first establishment instituted by any European", Topping p. 2.
[160] Topping p. 2, Michie-Smith (a).
[161] Love, Vol. III p. 347.
[162] Phillimore Vol. I, p. 172.
[163] See the following section. Goldingham was also an assistant to Petrie for some time and later assisted Topping in his surveying work.
[164] Phillimore Vol. I, p. 174.
[165] Phillimore Vol. I, p. 173. See also Love Vol. III p. 417, where Topping's row with Major Manle on his design of the observatory is also dealt.
[166] Topping P. 5, see for the inscription on the pillars.
[167] In the words of Sir Archibald Campbell, cf. Love, Vol. III p. 346.
[168] Phillimore Vol. I, p. 173.
[169] Goldingham.
[170] Phillimore Vol. II, p. 196.
[171] Goldingham.
[172] Michie-Smith (a) p. 2, see also J. Elliot, Climatological Atlas of India, (1), see Introduction.
[173] Phillimore, Vol. III (1815-1830), esp. p. 186-187. See also ibid Vol. IV, (1830-1843) p. 115.
[174] Phillimore Vol. II, p. 196
[175] His father Thomas Taylor, was the first assistant at the Royal Observatory and Taylor jr. took actually the profession of an astronomer on Pond's suggestion; Phillimore Vol. IV, p. 469, see also Markham p. 329-330, D.N.B. Vol. 19, p. 471-472.
[176] Cf. Taylor.
[177] Herschel. esp. 27.
[178] Op. cit. D.N.B. 19, p. 472.
[179] *Ibid.*
[180] D.N.B. Vol. 10, p. 560.
[181] Cf. section 3.5, for his work at his private Observatory at Poona.
[182] *Ibid.*
[183] He engaged himself in observation of proper motion of 400 stars, Markham p. 33.

[184] See Ansari (3), p. 245 where inadvertantly it is stated that Tennant took charge from Jacob.

[185] Cf. Herstmonceux Archives, Airy papers, Record No. 743 (1859-60), New signature K8. There are a number of letters of Tennant to Airy in this lot, e.g. dated Jan. 19, March 26, July 7 (1860). In these letters he corresponded directly with Airy on personal level, rather on official level through the Government.

[186] Cf. Printed records: Public (Home Dept.) Proceedings, Dec. 18, 1869, attached therein the letter from Col. J. T. Walker to Under Secretary, Govt. of India, dated Feb. 11, 1870, p. 1-2, item 6 and 8.

[187] Op. cit, his letters to Airy.

[188] He was elected as member of RAS already in 1855, see his obituary notices in *Proc. Roy. Soc.* 92 (1916), x-xiv and *Mon. Not. R.A.S.* 76 (1916) 272-76. In the following we utilise these obituaries.

[189] He got excellent result even by using wet colloidal plates. In fact he became such an expert in Photography that he was chosen as British delegate to the Astrographic Conference, held at Paris in 1887, ibid, *Mon. Not. R.A.S.*

[190] Cf. *Mon. Not. R.A.S.* (1872) p. 254, quoted in his obituary notice *Mon. Not. R.A.S.* 76. (19 esp. p. 275. It may be noted that his correct conclusion that Corona is the atmosphere of the Sun was indirectly against the prevalent ideas about its origin as "a terrestrial, or perhaps a lunar phenomenon", cf. op. cit. *Proc. Roy. Soc.*

[191] *Mon. Not. R.A.S.* 76 (1916), p. 275-276. He published about 50 papers in *Mon. Not. R.A.S.* and 5 in *Memoirs R.A.S.*

[192] Michie-Smith (1)

[193] He had been even the Director of John Lee's Observatory at Hartwell; cf. Markham p. 331, D.N.B. Vol. 16, also *Mon. Not.*, 52 (1892) 235-237.

[194] D.N.B. Vol. 16. See below in the following footnote.

[195] Markham p. 332-34. It is strange that in *Encyclopaedia Britannica* (Vol. 2, p. 634, entry 'asteroid') Pogson's discoveries are not mentioned. Some other minor planets discovered by him are: Amphitrite (1854), Isis (1856), Ariadne (1857), Hestia (1857); also Vera (1885); see Shearman, esp. p. 483. For the discovery of Isis, he was awarded the Lalande medal of French Academy.

[196] The principal variables discovered by him are: *R & S Ursae Majoris; R. Libra; U Scorpii; T. S.* and *R Ophiuchi; T, R & S Sagittari; R Cygni, R Cephei, U Capricorni, R Cassiopeiae;* Shearman, p. 483.

[197] Cf. the following section.

[198] D.N.B. Vol. 16.

[199] Markham, p. 332. He also found in 1860 independently a new star in the globular cluster in *Scorpio*, i.e. Messier 80; Shearman, p. 481.

[200] *Ibid*, p. 335.

[201] D.N.B. Vol. 16.

[202] He was however not satisfied and longed for being the Felllw of The Royal Society. See also section 5 for his dissatisfaction and difficulties. It may be mentioned that he had an active correspondence with Astronomer Royal Sir George Airy.

[203] Madras Mail. ,

[204] From 1899 to 1915 he was the director of Kodaikanal Observatory.

[205] Michie—Smith (1), p. 3.

[206] Elliot, P. 11.

[207] *Ibid.*

[208] To this decision of the Government, the Madras Famine of 1876-77 had also contributed, since the enquiry commission of the Government had confirmed a correlation between the seasonal distribution of rains in India & the Sunspot periodicity. Sir Norman Lockyer's role in establishing this correlation on world-wide basis has been dealt in detail by Meadows, see esp. p. 125 et seq. We may however mention here his *Memorandum* in which he described his efforts to establish the Solar Physics Observatory. Quoting the European Examples of Solar Research done at Potsdam, Paris, Rome and Palormo etc., where the observations were often interrupted due to climate, he cited the "state of things.... in India, ...(where) one can obtain observations of the finest quality in sufficient quantity all the year round.." He then pleaded at least for a good photograph of the Sun's disc in India. In fact he succeeded in getting a hell erected at Dehradun, where one Mr. Meins (trained by him at South Kensington) began taking solar pictures already in 1878, Lockyer p. 19-20.

[209] Francis, p. 373.

[210] I.M.D. (2), p. 2-3; see also the obituary notice, Michie Smith (2).

[211] It may be added that in seventies the Kodaikanal Observatory ceased to be under the supervision of the Indian Meteorological Department. It is now one of the constituent observatories of the Indian Institute of Astrophysics, Bangalore; see the Contribution of Bhattacharya in this voluma.

[212] Markham, P. 340.

[213] E.B. (1966) Vol. 12, P. 847.

[214] The Madras Observatory is neither indexed (ibid, vol. 23), nor even mentioned in the entry 'Madras' (Vol. 14, p. 556). Only in Vol. 16, p. 832, entry 'Observatories', its year of establishment (1792) is mentioned under 'Solar Physics Observatory'. In the section 'Colonial Observatories' (Vol. 16, p. 829) where it could have been treated, it does not occur at all. In the edition of 1932, i.e. (E.B. (1932), Vol. 13, p. 473), under 'Kodaikanal', it is however mentioned that "it contains a government observatory, well-known for investigation in terrestrial magnetism, seismology and Solar Physics". Just by three lines the "history" of Kodaikanal observatory is disposed of in E.B. (b) Vol. 16, p. 674, ubder "Modern Observatories of 20th century.

[215] Phillimore Vol. III, P. 187.

[216] *Ibid*, p. 188.

[217] *Ibid*, p. 189, for biographical sketch see ibid vol IV. Emphasis our. Waugh is perfectly right in using the word *appendage*. In fact the whole astronomical activity was subservient to geography and/or navigation and later to the dictates of the Astronomer Royal, see Section 4. In other words astronomy was not promoted as a scientific discipline by the then Govt. of India, see section 5 for its science policy.

[218] Phillimore Vol. III p. 188, Bose et al p. 512.

[219] For a sketch of that theodolite, see Bose et al, p. 513.

[220] His researches were published in *J. Asiatic Soc. Bengal* 9 (1840) 75-80 and *Memo Roy. Astron. Soc.* 3 (1829) 344-58, as quoted by Phillimore Vol. III P. 189.

[221] Phillimore Vol. IV. P. 113.

[222] Report of the Council.

[223] Thornton P. 311.

[224] But he did not attribute the same distinction to Madras.

[225] 'Alī, p. 21. 'Alī gives also a photograph of this *Kothī*.

[226] Nevill, P. 152, 208-210.

[227] Markham, P. 328.

[228] Phillimore, Vol IV, P. 215 et seq.

[229] Ansari (3), esp. p. 249. The present section is based more or less on that account. We have tried to upgrade that account, to some extent due to lack of time at our disposal, by drawing on new material.

[230] Haydar, p. 40 et seq. The first edition is not available to us. For an English translation of the relevant portion see, original records F(P)C, No. 130-136, Oct. 6, 1849. Hereafter we use the following notation: PC for 'Political Consultations' and F(P)C for 'Foreign (Political) Consultations'. It may be mentioned that Ḥaydar completed his history already in 1848-49, but could not publish it. The author of this article has seen the original manuscript of this work, in Lucknow recently. It is in the possession of Mr. Ra'īs Āg͟hā (Editor of 'Ajam), Gola Ganj, Lucknow. The account of the observatory therein is a bit different from the one in the printed one. According to this manuscript the birth & death years of Haydar are 1794 & 1881.

[231] Letter from King of Avadh (the wrong English Orthography is Oudh, which we will have to use, since it is found in the records) to Assistant Resident in Lucknow (in Persian), dated Sept. 8, 1831, English translation in PC, No. 31, Oct. 28, 1831.

[232] Capt. J. W. Herbert (1791-1833) was then the Deputy Surveyor General and Superintendent of the Revenue Survey. He was especially known for his leading part in the activities of the Asiatic Society of Bengal and was the editor of "Gleanings in Science"—the forerunner of the "Journal of the Asiatic Society of Bengal", Phillimore, Vol. IV, P. 457-458.

[233] This was quite a generous sum. Compare it with that of the Government Astronomer at Madras, namely, Rs. 800 per month; see Pogson's letter to Airy, Dec. 2, 1876; Airy correspondence on observatories, No. 749 (New classification), Herstmonceu. Archives. We shall discuss this point in Section 5, on Science Policy.

[234] Kamāluddīn Ḥaydar, the above-mentioned historian, was appointed as a translator. He claimed to

have translated 19 works in Urdu, Haydar, p. 42. Several of these available in well-known Indian-libraries, e.g. Salar Jung Museum Library at Hyderabad Khuda Bakhsh Library, Bankipur (Patna).

235 PC, No. 31 Oct. 28, 1831, Letter from Assistant Incharge to Governor General through the Secretary of Govt. of India. Hereafter without these details only the reference will be given.

236 Phillimore Vol. IV, p. 115-116.

237 Mrs. Herbert a native of Oudh was presented a generous grant of Rs. 10 000 by the King on his own desire, PC, No. 71 of Dec. 5, 1833.

238 On the request of the King, the Governor General selected Major Wilcox out of a number of applicants, "on account of his scientific acquaintance and general good character," PC, No. 37, Feb. 1, 1834, No. 48 of Jan. 15, 1835 and No. 2 of Feb. 5, 1835. Wilcox was the first assistant under Maj. Everest of the Grand Trigonometric Survey. Wilcox was appreciated for his "temper and principles", PC, No. 1 of Feb. 5 1835. According to Waugh, "he had, moreover, another rare qualification which....pre-eminently fitted him for the post of Astronomer at a native court. He was a distinguished oriental scholar," Phillimore, Vol. IV p. 115. See biographicak sketch, Phillimore Vol. III.

239 As far as we know this source material has been utilised for first time by

240 F(P)C, No. 171, Aug. 10 (1842). It is an interesting point to be treated elsewhere.

241 Report of the Council.

242 Wilcox, V.

243 Wilcox, IV. The same equipment is also given in his letter to the President RAS, dated July 11, 1839 (RAS Archives).

244 Wilcox, VI and VII. Cf. Sprenger's letter, where he remarks that "the mural circle and transit instruments are facsimiles of those at Greenwich, Phillimore Vol. IV, p.116. Cf. also Haydar (p. 40) according to whom the instruments were model as those at Greenwich Observatory and were brought from London. Note his estimate of the Observatory: on building Rs. 4,50,000, on Pillars for telescope Rs. 50,000 and on Instruments Rs. 1,00,000, totalling Rs. 6,00,000—£60,000 according to the then prevalent rate.

245 Phillimore, Vol. IV, p. 116. Emphasis above are ours.

246 Cf. Section 3.3.4.

247 Phillimore Vol. IV p. 116. For Waugh see section 3.2.

248 Report of the Council.

249 Jacob (1).

250 Besides Astronomer Royal Sir George Airy with whom he had an active correspondence he was also in communication with Cap. Boileau (Simla), Luit. Ludlow (Madras), Secretary and President of Royal Society, Sir John Herschell etc., Letter of Wilcox to Resident I. Low, FC, No. 110, Aug. 2 (1841).

251 Letter dated July 10, 1841 at Herstmonceux Archive, Old call No. class K, Shelf 1, No. 1. cf. also section 4.3.

252 Wilcox, V.

253 Wilcox, VII, see also Report of the Council.

254 Cf. his letter to President RAS (dated July 11, 1839) in which he promised to communicate "the approximate latitude and longitude of it (the observatory), the former determined by an 18" transit circle, the latter from upwards of 50 eclipses of Jupiter's first satellites and the transit of moon..."; (RAS Archives).

255 Wilcox, V.

256 Wilcox, IV, cf. also Report of the Council.

257 Wilcox, VI.

258 Wilcox, VII.

259 Report of the Council, where Springer's letter dated Sept. 1849 from Lucknow is printed.

260 Wilcox, IV.

261 Report of the Council, P. 91.

262 VINCE was Plumian Professor of Astronomy and Experimental Philosophy at Cambridge. The second edition of the book (252 pages) was published in 1801. It is available in the Library of RAS (London). The printing of the Urdu translation, however, was not completed according to Kamālludīn Haydar's account.

[263] Wilcox, II. Out of 21 listed translations in Urdu, only five were printed (at Delhi and/or Agra), for instance that of Brougham's book. The translations were from various fields, e.g. physics, chemistry and astronomy. As mentioned before some of them are extant as manuscripts, for instance at Hyderabad. Cf. also sec. 6.

[264] Wilcox, VII. He stated that the translation was then being printed in King's lithographic press.

[265] It is regretted that in Ansari (3), the date is wrongly given as Oct. 25, 1848, which is the date of his will, phillimore, Vol. III, see biographical notes.

[266] This date is mentioned in Haydar, p. 45. But according to a letter from the Resident at Lucknow to the Secretary, Govt. of India (dated Sept. 13, 1849), the date of actual abolition was Aug. 8, 1849; cf. F(P)C No. 130-136, Oct. 6, 1849. It appears to us as the correct date, see in the next paragraph above captain Strange's meeting with Kālī Charan.

[267] Reply of the King to the Resident's letter of Aug. 18, 1849, dated Sept. 14, 1894 F(P)C No. 130-136, Oct. 6, 1849. Haydar (p. 44) gives the total cost incurred in as Rs. 19,00,000. Recall the total initial cost of the establishment as Rs. 6,00,000 Haydar p. 40.

[268] Haydar, p. 44.

[269] F(P)C No. 130-136, Oct. 6, 1849. It is true that in the printed version (of 1896) it is stated that his *History* was sponsored by Henry Elliot. Consequently it is possible that Ḥaydar had to praise Elliot more than the King of Oudh. Recently we had a discussion with Ra'īs Āghā on this point, the owner of the original manuscript of the History. Ra'īs Āghā is of the opinion that the original version is different from the printed one, it was submitted to the Resident to secure the permission for publication and as a result Haydar had to carry out some modifications for the Resident's accord. Āghā intends to publish this *history* shortly.

[270] Phillimore, Vol. IV, p. 116, where the report of Strange to Surveyor General is cited as: dated 12.2. 1856, Dehra Dun Survey Records 601 (184).

[271] *Ibid,* p. 116. Emphasis ours. Strange met at the Observatory Kali Charan (one of the Indian assistants or 'Computer' of Wilcox), according to whom regular observations carried out "continuously and uninterruptedly" by mural circle and transit from S 1841 to Aug. 6, 1849, "The day upto which I (i.e. Kali Charan), was there" (ibid, In other words, just short of one year after the death of Wilcox, the observatory *in operation,* and the Indian assistants of Wilcox continued to carry out its programme which according to Waugh (ibid p. 115) consisted of "chiefly planetary lunar (observations), and therefore difficult to reduce", Despite the difficulties the Indians were carrying out the reduction!

[272] Markham, p. 328, where the original reference is given as *Proc. Astro. Soc. 17,* p. 63. Phillimore, (Vol. IV, p. 117) quotes *Monthly Notices* of RAS, 18 (1858) 287.

[273] Markham, P. 328.

[274] Archives at the Royal Society Library, call number MA 255. It may be added that WILCOX was especially asked by the Resident for such observations, PC, No. 136 of May 18 (1840), see also a discussion on this point in section 5.

[275] Phillimore, Vol. IV P. 116.

[276] Haydar, P. 44.

[277] Letter of Sprenger to RAS, dated Sept. 14, 1849, printed in Report of the Council esp. 92.

[278] He had seven children, the executor of his will dated Oct, 25, 1848 (three days before his death) was his deceased wife's brother Mr. Thos Wilson of Ghazipur; Phillimore, Vol. III, biographical notes.

[279] Probably Verma according to present orthography.

[280] Broun (1), see especially the prefaco.

[281] Markham, p. 337. The role of individuals, like Topping and Caldecott, in starting modern astronomy in India should be noted.

[282] D.N.S., Vol. 3, p. 690-691.

[283] Besides these Caldecott also purchased instruments for magnetic and meteorological work. On his return to Trivandrum in 1841, a magnetic and meteorological observatory was also established, which was later shifted to the peak Agustia Malley (or Mullaly) see, ibid and Broun, op. cit.

[284] Caldecott's observations of 1845 were employed by Hind to calculate the orbit of comet, see D.N.B. *op. cit.* for original reference.

[285] D.N.B. Vol. 3, p. 69.

[286] Cf. Markham, p. 282, footnote 2, they are also listed in D.N.B. op. cit.

[287] Broun came from Sir Thomas Brisbane's Observatory at Makerstown (Scotland) of which he was the director. This observatory was established by Thomas Brisbane's (1773-1860) in 1841 for taking magnetic observations in Scotland, since Brisbone was a keen supporter of Humboldt's movement of world-wide magnetic observatic see D.S.B., Vol. II, p. 471.

[288] Broun (1) & (2). He has reported his work, for instance, in the *Transactions the Royal Society of Edinburgh, Proceedings of the Royal Society, British Astronomical Association Reports and Comptes Rendus.* On the basis of his excellent work Broun won the Keith Biennial Prize and was elected as Fellow of the Royal Society; see Markham, p. 338-339.

[289] Jacob (1) where more details of construction are given.

[290] Jacob (1).

[291] Jacob (2) and (3). See also D.N.B., Vol. 10, p. 560.

[292] Cf. sec. 3.1.4.

[293] A meteorological observatory was founded by the East India Company at Colaba (Bombay) in 1823: see details Markham p. 285 et seq.

[294] Markham, p. 339.

[295] His grandfather Jamsetjee Dorabjee Naegamvala (1804-1882) had been praised by H.G. Briggs (assistant secretary to G.I.P. Railway in Bombay) as "the native pioneer of railway construction in India", see his biography (p. 7) by Nowrojee K. D. Naegamvala, son of K. D. Naigamvala—the astrophysicist and director of the observatory. Naegamvala in his booklet also gives a short life sketch of his father. The author has the privilege to see him at Poona in 1976, when he was 80-85 years old.

[296] In fact Naegamvala *was the first astrophysicist India has produced.* He was followed by M. N. Saha in his century; see also Ansari (g), in which his work highlighted for the first time.

[297] See section 3.6.2 for some details.

[298] He has been also a fellow of the Chemical Society and also of the Institute of Chemistry; cf. family papers. The author is extremely indebted to Dr. Sillo M. Vachha (grand-daughter of K.D.N.), her mother and Mrs. M. P. Naigamvala for the permission to see the Family papers. An interview with Mr. J. P. Naigamvala (grandson of K.D.N.) is also acknowledged gratefully. Typescripts & hand-written drafts, original papers of Naigamvala will be referred to hereafter as family papers; other records are extant at Maharashtra Govt. Archives at Bombay.

[299] Family papers, a draft of 5 foolscape pages. See, records (Education Dept.) No 4906 dated Nov. 2, 1882 where with reference to the University Calender for 1881 it is stated "that the Chancellor of the University has suggested......the state of natural science and the present offer appears to be a response to that suggestion. However, the words quoted above from the family papers are exactly the same as given in Raja's letter of offer, see records (Education Dept.) No. 738, 1882. Naigamvala in fact claimed to the inception and development of the observatory, see his pri Memorial to William Baron Sandhurst (Governer of Bombay), dated April 6, 1899.

[300] Bombay Records (Education Dept.) No. 738, 1882.

[301] Father A. Secchi (1818-1878) was the director of the observatory of the College Romano. He also founded the Societa degli spectroscopisti Italiani in 1867, see Todd, p. 252. See in this connection Pennekock p. 389.

[302] See section 3.7.

[303] Sir Norman Lockyer was also trying hard to establish a Solar spectroscopic observatory since 1877, when he submitted his Memorandum.

[304] Sir Norman Lockyer was appointed Professor of Astronomical Physics in 1882, sec Lockyer (a), *Memorandum,* p. 25. Besides spectroscopy, astronomical physics also included photography, discovered in 1839. Cf. section 3.1.7 where Michie-Smith's (a, complaint is quoted on the "new astronomy".

[305] Bombay Records, Education Dept. Vol. 10, No. 244 (1884).

[306] *Ibid,* No. 441 (1886).

[307] Bombay Records, (Education Dept.), No. 441, 1886, see especially his memorandum dated May 4, 1886.

[308] Family papers, draft dated May 28, 1888. See also Bombay Records, Education Dept. No. 1464, Aug. 10, 1888.

[309] *Observatory,* XI, No. 143 (1888) p. 438.

[310] *Ibid.*

[311] Naegamvala (1) & (2).

312 Cf. sec. 3.1.7.
313 Naegamvala (2).
314 Christie (1).
315 To plan an expedition in the interior of the countryside was then not so easy. "The country in the vicinity of Jeur was,.., flat, almost devoid of trees except a few scraggy *babuls*, and the supply of water was not plentiful. Plague had also appeared in *Karma'la'*, the chief town of the *ta'luka'* (sub-district), but had not spread to the surrounding villages," Naegamvala (6), p. 3.
316 Bappu p. 9.
317 Naegamvala (6). We intend to review his report and other astro-physical work elsewhere shortly.
318 Naegamvala (4).
319 Naegamvala (3).
320 Meadows (1) p. 6.
321 Meadows (2) p. 232-233.
322 Naegamvala (2).
323 Lockyer, (1) p. 36, also discussed by Meadows (b) op. cit. For the review of this report, see *Indian Engineering*, Feb. 18, (1899), editorial, p. 97-98.
324 Naegamvala (5) p. 6.
325 Bappu, (3), p. 13, emphasis ours.
326 Lockyer (1) p. 21.
327 Naegamvala (5), p. 3-4.
328 Bombay Record, No. 799 (1899) Education Dept., dated June 23, 1899 Accompaniment No. II, Minutes by J. Nugent dated April 21, 1899.
329 Cited from a review of Lockyer's Report in the RAS journal *Observatory*, 1282 (1849) 7-309. cf. also Family Papers, a three-pages printed memorial, p. 2. See also section 3.1.7., Michie-Smith was appointed the director of the Astrophysical Observatory later.
330 On the basis of Bombay Records, we intend to deal this question elsewhere.
331 Bombay Archives, Education Dept. Vol. 10. No. 244 (1884).
332 Cf. Father de Penarande's report as cited by Naegamvala (3) 4th entry, p. 502.
333 Fa. Goreux, private communication, dated April 4, 1977. Records of some of them still extant at the College. The author is grateful to Father Goreux (Head, Dept. of Maths., St. Xavier College (Calcutta) for the information.
334 The Observatory could not compete the Meteorological Observatory, built at Alipore later, Goreux, *ibid.*
335 Goreux, ibid.
336 S. Ganguli, *private communication*, dated May 9, 1977. The author is thankful to Prof. Ganguli (Head, Maths. Dept., Presidency College, Calcutta) for this much of information.
337 Lt. Col. M. G. Arur (Director Geodetic & Research Branch, Dehra Dun), private communication, dated March 3 and April 11, 1978. The author gratefully acknowledges his academic cooperation.
338 Lockyer (1) p. 24-25. See also Col. St. G. C. Gore's report on Solar photography of 1901-1902.
339 Cf. E. B. (1966) **19**, p. 673, also *Records of Rs*, p. 271 et seq.
340 The Indian Advisory Committee of RS functioned was appointed in 1899 and later it functioned as a standing committee till 1923, see Macleod for details.
341 It may be mentioned that this committee by its resolution's on Oct. 26, 1892 (Chairman) Lord Kelvin and on July 20, 1893 (Chairman: President of RAS) approved the establishment of a solar physics observatory at Kodaikanal under the directorship of Michie Smith.
342 Cf. The *Records* of RS p. 271-272.
343 Details of their influence will be discussed elsewhere.
344 The transit of Venus in 1761 was recorded by a mariner, B, Plaisted (d. 1767), at Chittagong (now in Bangladesh). Nevil Maskelyne calculated from this observation the longitude of Chittagong town (also called Islamabad) as 91°45′. This value falls short of the correct one by 5' only, Phillimore Vol. I p. 152-153.
345 Cf. section 2.3, also Phillimore Vol. I, p. 155.
346 *Ibid* p. 376. In fact AR advised Rennel on the request of the Governor of Madras, Clive, who was a relation of Maskelyne.
347 Quoted in Phillimore, Vol. II p. 266.

348 Playfair reviewed the work of Lambton, in *Edinburgh Review* (1813), when it was communicated to him by Maskelyne; see Markham p. 69, Phillimore, Vol. II, p. 266.

349 He wished to base his surveying work on "correct mathematical principles". He was actually the first to propose the trigonometrical surveying in India in Dec. 1799 just 8 years after the General Trigonometrical Survey began in England (see E. B. Vol. 19, p. 674) Lambton's work was in fact, the forerunner of the Great Trigonometrical Survey started in India on April 10, 1082, see Phillimore, Vol. II Chapter 17 & 18, also Markham, p. 59-60, 63, 66.

350 See section 3.1.3. So far as John Goldhingham is considered, he "....was (not) in communication with European astronomers during the active part of his life", quoted in Phillimore Vol. II p. 402.

351 In the archives of RAS (London), there are some papers on Taylors; "section" 18.

352 We shall touch some of it below and in the following section. We intend to publish an account of Pogson—Airy correspondence elsewhere.

353 Airy.

354 *Ibid.*

355 RGO Correspondence (Observatories), No. 746 (1866-69) (Herstmonceux Archive).

356 *Ibid,* dated Oct. 2, 1866.

357 Public, Home Dept. Proceedings, Dec. 18, 1869, No. 227 (printed), available at Herstmonceux archive in No. 747, see also Markham p. 335-336.

358 Public, Home Dept. Proceedings, Op. Cit. No. 228, see also Markham 335-336. We shall not go to Mr. Pogson's criticism of that *Code of Instructions,* which were drawn by Lt. Col. J. T. Walker (of Survey of India.)

359 Home Dept., No. 80 of 1867; Simla dated 10.5.1867, p. 9. It is Pogson's reply. Proceedings of the Madras Govt. (Public Dept.) of 11.2.1866. It is a 10-pages report with two star charts (consulted at Herstmonceux archive, No. 746 (old No. ? of 1866-1869.

360 Meadows (2) p. 232.

361 Christie (1).

362 Christie (2). This is a report on the 1898 Solar Eclipse expeditions to India sponsored by the Joint Eclipse Committee of the Royal and Royal Astronomical Societies.

363 Christie (3) In all probability Christie must have been asked by observatories committee of which he was the Vice-Chairman, to inspect the Indian Observatories and to give his opinion on Eliot's proposal. The Report consists of nine sections and is 17 pages of fool's cap size.

364 Cf. Eliot for details of his scheme.

365 Christie (3), p. 13, see for modification p. 14-15.

366 *Ibid,* section 9, p. 16.

367 Lockyer (1). The *Report* is extant at Indian Office (London), Ref. No. IOR, L/E/7/42. The author thanks the Librarian for putting at his disposal a copy of the *Report.*

368 See Christie (2). There were actually four parties of observers; Lockyer was stationed at Vizidrug, *Christie* and Turner at Sahdol, Capt. Hill and Newal at Pulgaon and the fourth party was that of Copland. Besides RS and RAS, the British Astronomical Association also sponsored a few expeditions, in which Evershed and Michie Smith of Madras took part. See for details Maunder, P. 168. We may also recall here that Naegamvala of Poona College of Science with a large party of observers was stationed at Jeur (S. E. of Poona), where American and Japanese parties were also present. The Indian eclipse of Jan. 22, 1898 was no doubt the most important one from the point of view of coronal photography.

369 Lockyer (1) p. 32-33, p. 37.

370 John Evershed took charge of the Kodaikanal Observatory in 1911 and a new era on astrophysical research began in India.

371 See Kumar, Sangwan, MacLeod for the recent work.

372 Ansari (1) in which these ideas were developed for the first time, see also Ansari (4).

373 See section 3.6.2.

374 Pogson (5), section 6, p. 10. See also Pogson (b).

375 Pogson (6), Pogson (a), p. 4.

376 Pogson (7).

377 Lockyer (1) p. 36.

378 Tennant to Lockyer quoted in Meadows (b).

[379] PC, No. 136, May 18 (1840).
[380] Wilcox to Caulfield.
[381] The registers have been found by the author at the Library of the Royal Society, see Wilcox to Herschel, Sept. 1844-April 1845, (Call No. MA 255), monthly observations from June 1842 to May 1844.
[382] Pogson (5), p. 9.
[383] *Ibid*, p. 10. The coercion of then Colonial Government not to promote the *science* of astronomy is self-evident.
[384] See O'Malley, who has devoted a full chapter (XI) on "Muslim Cultural and Religious Thought", in which he discusses particularly the receptivity of the Muslim mind to European knowledge.
[385] These ideas have been developed in some details in Ansari (b).
[386] See for example, Carmody.
[387] Cf. Bernal, Vol. 2, p. 379 at seq.
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[389] See Bhattacharya's contribution in this volume for details.

13. ASTRONOMY IN INDIA IN THE TWENTIETH CENTURY.

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